Katholieke Universiteit Leuven
Faculteit Bio-ingenieurswetenschappen

DISSERTATIONES DE AGRICULTURA

Doctoraatsproefschrift nr. 750 aan de faculteit Bio-ingenieurswetenschappen van de K.U.Leuven

Improvement of collective water management in the Office du Niger irrigation scheme (Mali): Development of decision support tools

Proefschrift voorgedragen tot het
behalen van de graad van Doctor
in de Bio-ingenieurswetenschappen

door

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Improvement of collective water management in the Office du Niger irrigation scheme (Mali): Development of decision support tools

Promotoren:
Prof. Dirk Raes, K.U. Leuven
Dr. ir Jean-Yves Jamin, CIRAD, Montpellier

Leden van de examencommissie:
Prof. Guido Volckaert, voorzitter
Prof. Eric Tollens, K.U.Leuven
Prof. Ronny Swennen, K.U.Leuven
Prof. Frans Huibers, Wageningen Universiteit
Ir. Yacouba Coulibaly, URDOC/Office du Niger

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Preface

This PhD research was forged as a collaboration between K.U.Leuven, my Alma Mater, and CIRAD in Montpellier, which has an impressive track record of research for development. When Pierre-Yves Le Gal of CIRAD proposed the Office du Niger irrigation scheme in Mali for the case study, I said yes. How exciting! I knew almost nothing about this country, but would be able to discover all the more! It took however almost a year of writing and rewriting research proposals before I could actually set foot in Mali. Research money was still uncertain when Dirk Raes, my promoter from K.U.Leuven, and I finally decided to carry out an on-site inspection and hopefully force a break-through. So Jean-Yves Jamin, my co-promoter from CIRAD, arranged a one-month stay at URDOC. This was a local research center in Niono, the lively heart of the irrigation scheme.

I disembarked in Niono, where I was warmly welcomed by Paul Kleene, then technical assistant at URDOC. He generously offered his guidance and arranged numerous meetings with the stakeholders involved in the irrigation scheme. I also met Loïc Eliës, who had just started his own project, VISION, at the Office du Niger headquarters in Ségou and lobbied for my research work as enthusiastically as for his own project. We visited many of the people on the list of Paul Kleene together and as such started a much-appreciated cooperation.

Later on, Dirk joined me in Niono, and in spite of dozens of flee and mosquito bites, we managed to write a brand new research proposal. It was still not the last, but it was miraculously well received by at once the K.U.Leuven, CIRAD and the Office du Niger. This meant the go-ahead for the research, and a little later, Jean-Yves Jamin secured the necessary financial funds to sponsor the journeys to Mali and logistics in the field. Importantly, the proposal also got the interest of Yacouba Coulibaly, head of URDOC, who agreed to host the research project in its office in Niono. This proved to be crucial for the PhD research, and I owe it to Jean-Yves who introduced us to each other. Yacouba Coulibaly was my mentor and friend in Niono. Through his advice, he helped me focus on what is both realistic and important for improving water management in the Office du Niger and averted many diplomatic mistakes. He also generously shared the facilities of URDOC and his practical experience in doing research in the area.

So off I went, naïveté abound, to live and work for six months a year in Niono. The first year, I was lodged in the “case de passage” in Niono, together with the national trainees of URDOC. The culture shock was complete, but the experience unforgettable. We also had lots

of fun, not in the least when in the evening, power breakdowns forced us to play cards by candlelight. The house saw multiple improvements throughout the year: the hole in the ground changed for a toilet, the bucket for a shower and after a while, we were able to tap the signal from the neighbor's satellite dish on our TV. Meanwhile, I roamed the irrigation scheme on my motorbike, interviewing farmers and Office du Niger staff, and tried to get a grip on the subject of farmers' water management. I hardly got much further than rewriting the research proposal.

For the second and the third year, I moved to the house of Paul Kleene, who by then had left Niono. This meant a great leap forward for my standard of living, with no power breaks and an air conditioner making the night temperatures tolerable. By then, I also knew precisely where I was going with my research, and unrolled the methodology I had prepared. It demanded more courage, perseverance and diplomacy than I had expected, but in the end, it worked. An IWT scholarship gave some extra financial clout for the fieldwork, which was very welcome and made an elaborate data collection possible.

From the start, Abdoulaye Keita was a member of my little research team, first in the frame of his master research on the social aspects of water management, and later as my direct collaborator. Through his courage for fieldwork, diplomatic talents and keen insight in farmers' minds, his contribution to this research is priceless. It was nice to share with him my passion for the topic of farmers' water management, not in the least because we both enjoyed discussing it endlessly, thereby deepening our understanding of it bit by bit.

Many others have joined our team for shorter periods and provided a significant input for this research through their work and by sharing their views. Leen Boeckx and Leentje Bastiaens spent several months in Niono for their master research and left a fond memory in many peoples' mind. The circumstances in which they lived and worked were not always easy, but their open mind allowed them to go with the flow and contribute to the good atmosphere of our team. Daouda Keita, Abdoualye Dembele, Mamadou Koné and Amadou Cissouma collaborated as interpreters or interviewers. In a day of interviews in the villages, there is lots of time waiting for people to arrive, and I was lucky to share it with such joyful and interesting people.

Of course, we all learnt the most from the farmers of the Office du Niger. We took hours of their time asking questions, and they generously extended us their warm, African hospitality. The water guards and staff of the directorates of the different zones of the irrigation scheme have also largely contributed to the data collection and gave their valuable point of view on results. At the Office du Niger's headquarters, we found the doors open, and many of its people have helped to construct this research. In particular, Souleymane Sidibé and Yaya Diarra supported us within the Office du Niger and towards its financial and technical partners.

In Niono, our research found a welcome home at URDOC. I quickly discovered that its staff was always prepared to help us out with the practical problems we encountered, and join us in the reflection on farmers' water management. Together with many others in Niono, they also made my life pleasant and interesting in Mali. If you think that Niono is an out-of-the-way place, you are mistaken. During my stays, I met many local and international experts, scientists and consultants working on or for the Office du Niger. They contributed to this work by sharing their expertise. On the other hand, Niono is quite far away from home, and I thank Loïc and Anne, Christian and Maité and Toon and Elly for their kind hospitality and for looking after me.

After the third year of fieldwork, Abdoulaye Keita and I got the ambition to put our knowledge and insights to use for the farmers of the Office du Niger. We found support for our projects and the necessary financial funds to accomplish them at the Dutch embassy and the Delegation of the European Commission in Bamako and more in particular from Jaap van der Velden and Géza Strammer. Bruno Lidon from CIRAD provided invaluable support during their realization.

Throughout the research, Dirk Raes and Jean-Yves Jamin proved to be very stimulating promoters. They gave me autonomy when I wanted it, and guidance when I needed it. They always believed in my research and in me as a researcher, which gave me the confidence to carry on. I also learned a lot from their feedback on the various drafts of the papers they co-authored, and finally on this dissertation. In their turn, the jury members read this work with much appreciated attention, and their comments improved it considerably. My colleagues in Leuven provided a fun working environment and the moral support of those going through the same process. With his persistent questions during lengthy discussions, Bruno Verbist helped me to see the connection again between the different papers I had been writing. Sofie Bruneel and Viviane Crabbé have lifted many administrative and practical obstacles, which I usually placed before them with a time constraint of just a few days.

During the years of this research, friends and family shared my small successes and setbacks and made them more important and less bad respectively. My parents also did this very enthusiastically, but their most significant contribution was indirect: From them I inherit the appetite to question, and the curiosity to explore. Finally, the most precious support came from Bart. With an infinite patience and sincere interest, he listened to my detailed reports on the field work, analysis and writing, and along the way, he had no choice but to become an expert himself on the topic of farmers' water management in the Office du Niger. This turned out to be quite convenient, as it made his input all the more relevant. It was a bit unfortunate that three weeks after I got together with him, I had to leave for my first long stay in Mali. Luckily, our love proved larger than the distance.

My gratitude and respect go to all these people and institutions whose path I crossed during the past few years, for the various ways in which they contributed to this research.

Klaartje

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Samenvatting

In de context van de structurele aanpassingsprogramma's wordt in vele ontwikkelingslanden onder druk van internationale donoren het beheer van publieke irrigatieprojecten overgedragen. De onderliggende assumptie is dat boeren betere beheerders zijn dan de inefficiënte bureaucratieën die ze vervangen, aangezien zij een onmiddellijk belang hebben bij een degelijk bestuur. Het hervormingsproces verliep echter dikwijls moeilijk en werd geplaagd door tegenslagen. Dit is te wijten aan een onvoldoende begrip over hoe deze irrigatieprojecten functioneren, wat een correcte implementatie van de bestuursoverdracht onmogelijk maakt. Dit onderzoek ontrafelt het waterbeheer door boeren na de overdracht via een gevalstudie in het Office du Niger irrigatieproject in Mali.

Het irrigatieproject is 80 000 hectare groot en rijst is er het voornaamste gewas. Grootscheepse hervormingen in de jaren 1980 en 1990 verdrievoudigden de rijstproductie per hectare en verhoogden de rendabiliteit van rijstproductie aanzienlijk. Gezien dit succes en een groot potentieel aan geïrrigeerd areaal, is een snelle uitbreiding van het irrigatieproject gaande. Wegens de groeiende druk op het water zal deze uitbreiding echter moeten gebeuren zonder een significante toename van de totale waterconsumptie. Dit kan als de irrigatie-efficiëntie, momenteel amper 25 %, verbetert. Een verhoging van de efficiëntie is vooral mogelijk op het tertiair niveau. Boeren zijn hier gezamenlijk verantwoordelijk voor het beheer van de infrastructuur en het water sinds de bestuursoverdracht. Volgens de internationale donoren en het centraal bestuur ligt een gebrekkig waterbeheer door boeren aan de grond van de huidige waterverliezen. Daarom werden verschillende projecten opgezet om de inzet van boeren voor waterbeheer te verhogen. Aangezien boeren geen belang hebben bij de uitbreiding van het irrigatieproject, zijn zij echter niet geïnteresseerd in irrigatie-efficiëntie. Hun strategie is om het rendement op arbeid te maximaliseren. Voor boeren is arbeid een schaarse productiefactor die verdeeld moet worden over verschillende bronnen van inkomsten. De huidige ongelimiteerde en vraaggestuurde waterverdeling laat hen toe een minimale inzet aan arbeid te combineren met een vlotte irrigatie. Enkel voor boeren wiens veld een onvoordelige ligging heeft, zou collectieve actie voor het reguleren van de waterverdeling binnen het tertiair niveau nuttig zijn. Deze verschillen in belangen liggen aan de kern van de huidige conflicten tussen boeren onderling, en tussen boeren en het centraal bestuur. Door middel van een veldonderzoek werden de relaties tussen collectieve actie, arbeid en irrigatie-efficiëntie onderzocht in het licht van de praktische en sociale beperkingen die het waterbeheer en de mogelijkheden tot verbetering mee bepalen.

Resultaten van het veldonderzoek geven aan dat dankzij de fysische rehabilitatie van de irrigatie-infrastructuur en de vraaggestuurde waterverdeling, de watertoevoer naar het tertiair niveau adequaat is. Irrigatieproblemen zijn dan ook zeldzaam, hoewel ze voorkomen in tertiaire blokken met een ongelijke topografie. Regels rond waterverdeling tussen boeren kunnen zulke problemen oplossen, maar wegens een gebrek aan sociaal kapitaal slagen sommige boerengroepen er niet in deze op te stellen en af te dwingen. Met een gemiddelde van 60 % blijft de irrigatie-efficiëntie zeer laag. Een verhoging met 14 % is mogelijk door middel van collectieve actie aan de inlaat van het tertiair blok. Het veldonderzoek bevestigde bovendien dat de lage efficiëntie excessieve waterverliezen veroorzaakt die het drainagesysteem opvullen, en zo een belangrijke oorzaak zijn van drainageproblemen. Op het moment van de oogst doen deze zich voor op een derde van de oppervlakte. Aangezien het drainagenetwerk bestaat uit communicerende vaten, wordt het resultaat van de inzet van een individuele boer om water te sparen verspreid over een groot gebied. Het voorkomen van drainageproblemen zorgt hierdoor niet voor de nodige motivatie om zuinig met water om te springen. Als men met de uitbreiding van het geïrrigeerde areaal wil doorgaan, moeten daarom andere manieren onderzocht worden om de waarde van het water te verhogen.

Een lopend project richt zogenaamde Associaties van Watergebruikers op, die een welkom platform zouden kunnen bieden voor collectieve actie. Voorlopig ontbreekt het hen echter aan effectiviteit. Door rekening te houden met bestaande informele patronen van besluitvorming zou hun impact wellicht kunnen verhoogd worden. De huidige trend van diversificatie van inkomsten leidt bovendien tot een toenemende tewerkstelling van landarbeiders, die dan ook bij de Associaties van Watergebruikers zouden moeten betrokken worden.

Om boeren in staat te stellen de Associaties van Watergebruikers ten volle te benutten en de uitdaging van waterbesparing aan te gaan, zijn vorming en beslissingsondersteuning nodig. In het kader van dit onderzoek werden hiervoor hulpmiddelen ontworpen. Een eerste hulpmiddel bestaat uit educatief materiaal dat aantoont hoe boeren water kunnen besparen en irrigatieproblemen vermijden bij een beperkt wateraanbod door bepaalde beheerspraktijken toe te passen. Een tweede hulpmiddel is een simulatiemodel van het waterbeheer, dat gebruikt kan worden om een optimale combinatie van beheerspraktijken te vinden om de irrigatie-efficiëntie tot op een bepaald niveau te brengen en tegelijk de belangen van de boeren te respecteren. In de toekomst zal verder gezocht moeten worden naar een passend beleid, aanbevelingen en hulpmiddelen. Hiervoor zal een proces van “trial and error” nodig zijn waarbij alle betrokken partijen elkaar regelmatig ontmoeten om lessen te trekken uit ervaringen. Onderzoekers kunnen in dit proces een positieve bijdrage leveren door hun meer neutrale en wetenschappelijke kijk op de zaak.

Résumé

Dans le contexte de l'ajustement structurel, les bailleurs de fonds ont imposé un transfert des responsabilités de la gestion de l'eau dans la plupart des périmètres irrigués des pays en développement. L'hypothèse de base était que, vu leur intérêt à la réussite des périmètres, les paysans seraient de meilleurs gestionnaires que les bureaucraties qu'ils remplaçaient. Mais du fait d'une mauvaise compréhension du fonctionnement de ces périmètres, le transfert a été souvent mal mis en œuvre et n'a pas engendré l'amélioration de l'entretien des infrastructures et l'usage rationnel de l'eau qui étaient espérés. Cette recherche a pour objectif d'acquérir une compréhension approfondie de la gestion de l'eau paysanne, à travers une étude de cas du périmètre rizicole de l'Office du Niger au Mali (80 000 hectares).

La gestion de l'eau au niveau tertiaire du périmètre a été transférée aux exploitants. Ce transfert faisait partie d'un éventail de réformes économiques et institutionnelles qui ont permis d'améliorer fortement la productivité des rizières et la rentabilité des exploitations agricoles. Vu cette réussite, et le potentiel considérable en terres aménageables, l'Office du Niger a lancé une extension de ses surfaces irriguées. Comme elle doit être réalisée sans une augmentation signifiante de la consommation en eau totale, la faible efficience de l'irrigation est considérée comme potentiellement préjudiciables pour l'extension prévue. Cette recherche analyse la gestion de l'eau par les paysans dans le contexte de leurs objectifs et stratégies, et des relations sociales et des évolutions économiques qui influent sur la prise des décisions en matière de gestion de l'eau. Les résultats de ces analyses sont ensuite traduits en outils et recommandations pour appuyer la gestion de l'eau par les paysans.

Les résultats de l'étude de terrain montrent que, grâce à la réhabilitation des infrastructures et au transfert de la gestion de l'eau, la disponibilité en eau est adéquate au niveau tertiaire. Avant les réformes, des pénuries d'eau étaient fréquentes et provoquaient des pertes de production. Par contre, avec une moyenne de 60 %, l'efficience de l'irrigation demeure très basse. L'étude confirme que les pertes d'eau qui l'explique sont une cause importante des problèmes de drainage rencontrés, qui affectent un tiers des surfaces à la récolte. Les stratégies des exploitants sont de maintenir en permanence une offre en eau excédentaire, afin de minimiser le besoin d'action collective et de travail individuel. Le temps de travail est précieux pour les exploitants, car ils doivent le partager entre plusieurs activités rémunératrices. Pour l'action collective, la disponibilité du capital social est un autre facteur contraignant. La tendance actuelle à la diversification des sources de revenu diminue

l'importance accordée à la gestion de l'eau et complique l'action collective. Les Associations d'Usagers de l'Eau qui sont actuellement établies dans la zone pourraient constituer une plate-forme pour institutionnaliser l'action collective, mais elles souffrent d'un manque d'autorité. Jusqu'à maintenant, ces aspects n'ont pas été suffisamment pris en considération par les politiques des bailleurs de fond et par l'Office du Niger. De plus, certaines étaient fondées sur des hypothèses inexactes sur l'importance de certains aspects de la gestion de l'eau pour l'efficience de l'irrigation. Par conséquent, elles ont eu peu d'effet.

L'extension des surfaces irriguées est importante pour les exploitants futurs, la croissance économique régionale et la sécurité alimentaire du Mali. Pour la permettre, l'efficience de l'irrigation devra augmenter. Les intérêts des exploitants actuels et les contraintes pratiques et socio-économiques qui freinent l'amélioration de la gestion de l'eau devront aussi être pris en compte. Les analyses effectuées ont permis d'améliorer la compréhension de la réalité technique autant que sociale de la gestion de l'eau et de formuler des recommandations. Le besoin d'un renforcement des capacités de gestion de l'eau et d'une aide à la décision sont les points les plus importants. Dans le cadre de cette recherche, des outils d'appui ont été mis au point. Un premier outil est constitué de matériel didactique pour montrer comment les conséquences d'une diminution de la disponibilité en eau peuvent être évitées grâce à certaines pratiques de gestion de l'eau. Un deuxième outil est constitué d'un modèle de simulation qui, à travers la simulation de différents scénarios, aide à trouve la combinaison optimale de pratiques qui permet d'atteindre un certain niveau d'efficience d'irrigation tout en respectant les intérêts des exploitants.

Dans le futur, la recherche de politiques appropriées, de dispositions et d'outils d'appui, nécessitera un processus itératif d'essais et d'erreurs incluant des rencontres régulières entre bailleurs de fonds, gestionnaires et exploitants pour évaluer les leçons à en tirer. Du fait de leur regard plus neutre et sans trop de préjugés, les chercheurs pourraient contribuer positivement à ce processus.

Summary

In the context of structural adjustment, international donors have pushed Irrigation Management Transfer (IMT) in state-led irrigation schemes all over the developing world. It was assumed that, having a direct stake in the success of their irrigation scheme, farmers would be better managers than the inefficient bureaucracies that they replaced had been. However, insufficient understanding of these irrigation schemes often led to poor implementation of IMT. The reform process proved complex and fraught with difficulties, and usually did not result in improved water management as expected. This research aims to acquire a thorough comprehension of farmers' water management after IMT through a case study of the Office du Niger, an irrigation scheme of 80,000 ha in Mali with rice as the major crop.

Comprehensive institutional and economic reforms conducted in the 1980s and 1990s boosted the profitability of rice production in the Office du Niger, with yields increasing threefold. In view of this success and the large untapped agricultural potential, the irrigation scheme is expanding rapidly. Because of growing pressure on water resources, the expansion has to be realized without a significant increase in total water consumption. This is possible if irrigation efficiency, currently at barely 25 %, improves. The largest potential for increasing efficiency lies at the tertiary level, where since IMT, farmers are collectively in charge of managing water and the infrastructure. In the view of international donors and the central management, poor water management practices by farmers are to blame for the current water losses. Therefore, several interventions were set up to increase farmers' efforts for water management.

As they have no stake in the expansion of the irrigation scheme, farmers are however not interested in increasing irrigation efficiency. Their strategy is to maximize returns to labor, which is valuable to them as it comes at the price of time available for other income generating activities. The presently unrestricted and demand-driven water delivery allows them to combine a minimal labor input with easy irrigation by maintaining a constant over-supply. For farmers with a disadvantageous plot location, collective action for regulating water allocation would be useful in times of temporary supply disruptions, but it requires sufficient social capital. This divergence of interests with respect to water management lies at the heart of the conflicts among farmers and between farmers and the central management. Through a field study, relations between collective action, labor input, and irrigation

efficiency are investigated in the light of the practical and social constraints that shape water management and determine its potential for improvement.

Results from the field study revealed that thanks to the physical rehabilitation of the irrigation infrastructure and a demand-driven water supply, water delivery to the tertiary level is adequate. As a result, irrigation problems are rare, even though they exist on some tertiary blocks with an uneven topography. It was furthermore shown that collective action for water allocation could effectively solve these problems. Lacking the social capital, some farmer groups, however, do not succeed in establishing collective action. Irrigation efficiency at the tertiary level, on average about 60%, remains low, but collective action at the inlet of the tertiary block can improve it with 14 %.

The field study furthermore confirmed that water losses caused by the low irrigation efficiency fill up the drainage system and are an important source of the drainage problems currently affecting a third of the surface at harvest. Because the drainage system consists of communicating vessels, the impact of an individual farmer's effort dissipates throughout the irrigation scheme. Avoiding drainage problems can therefore not provide the necessary incentives to save water. Other incentives to increase the value of water to farmers should therefore be considered if the expansion of the irrigation scheme is to be realized.

Water User Associations (WUAs) currently being set up in the irrigation scheme could provide a much-needed platform to institutionalize collective action, but are not yet effective. Taking into account existing informal patterns of decision-making could enhance their impact. The current trend of farmers diversifying their sources of income results in the increased employment of wage laborers, who should therefore be involved in the WUAs.

In order to enable farmers to respond to incentives and make full use of the structures and procedures offered by the WUAs, training and decision support on water management will be necessary. In the frame of this research, tools have been developed for this purpose. A first tool consists of training material that shows how farmers can save water and avoid irrigation problems under a limited water supply by adopting the right water management practices. A second tool is a simulation model, which can be used to find the optimal mix of measures to increase irrigation efficiency to a certain level while preserving farmers' interests.

The search for appropriate policies, measures and tools will probably require an iterative process of trial and error with regular meetings among stakeholders to evaluate lessons learnt. Providing a neutral and unbiased view, researchers could play a beneficial role in accompanying this process.

INTRODUCTION

The context of farmers' water management

In the 1950s and 1960s, a fast expansion of large publicly funded surface irrigation schemes took place in developing countries. In these schemes, smallholder farmers share collective irrigation infrastructure (Svendsen and Meinzen-Dick, 1997). The ambitious goals were to meet the rapidly rising demand for food and to stimulate economic development (Plusquellec, 2002a; Bolding, 2004). At that time, the common conviction was that such irrigation schemes needed a strongly centralized management. Given their public nature, the state usually assumed the management through governmental agencies (Meinzen-Dick, 1997; Ostrom, 1999). Farmers were considered as "beneficiaries" of irrigation services, and their responsibility did not extend beyond plot level (Meinzen-Dick, 1997; Shah *et al.*, 2002). The governmental agencies however quickly grew into over-sized and expensive bureaucracies that put a heavy charge on national budgets instead of fostering economic growth (GRET, 1991; Vermillion and Sagardoy, 1999; Diemer, 2002).

This situation was not unique for large irrigation schemes. In many developing countries, the state was heavily involved in the majority of economic activities, sometimes combining mismanagement with heavy costs and provoking budget deficits. In the wake of the debt crisis at the end of the 1970s and the beginning of the 1980s, international donors proposed the so-called Structural Adjustment Programs throughout the developing world (Rodrik, 1996). The objective of structural adjustment was to combat macroeconomic malaise and to promote growth through pervasive institutional and economic reforms (Dollar and Svensson, 2000). These reforms implied the sale of government enterprises, opening previously monopolistic sectors to competition, abolishing price regulation and trade restrictions and finally dismantling governmental agencies involved in agriculture and natural resource management (Dembélé and Staatz, 1999).

In collective irrigation schemes, the reform translated into Irrigation Management Transfer (IMT), which shifted powers and responsibilities from government agencies to farmers (Svendsen and Meinzen-Dick, 1997). The objective of the donors was to involve farmers in operation and maintenance of hydraulic infrastructure, financing, and decision-making on the cropping pattern and the physical and institutional layout of the irrigation scheme (Groenfeldt and Svendsen, 2000; Abdelhadi *et al.*, 2004). Government disengagement however also meant that subsidies were cut back, forcing irrigation schemes to become financially self-sufficient. As such, farmers pay for operation and maintenance through water fees. Significantly, international donors, not farmers requested these reforms.

Whereas the driving force behind IMT was structural adjustment, improving the performance of water delivery provided another argument for farmers' participation in water management. In this dissertation, performance is understood as an assessment of the actual results in comparison to the desired results. Results can refer to the output as such, or output in relation to input, considering the processes and procedures expanded to achieve the output. In water management, a first important aspect of performance is to get water to the crop on time and with the volume required. A second aspect is irrigation efficiency, which designates the ratio of net irrigation requirement to the amount of water supplied. The lower this ratio, the more water is lost through conveyance and/or application losses. Although part of the water losses might be reused downstream, some of it might evaporate or drain to the sea, a deep aquifer or another sink and as such is wasted in physical terms. In addition, passing through the irrigation scheme, all water losses represent sunk costs of pumping and might become polluted (Seckler, 1996).

In the 1980s and early 1990s, when IMT was at top speed, saving water was not yet high on the agenda. Gradually, it became however clear that the pending food crisis, triggered by fast population growth, is actually a water crisis (Worldwatch Institute, 2000; FAO, 2000; Rosegrant *et al.*, 2002). Indeed, since boosting agricultural output depends largely on irrigation, water becomes increasingly scarce through competition from households and industry (Rhoades *et al.*, 1999; Howell, 2001; Plusquellec, 2002b). Hence, the challenge of irrigation became to produce more with less water. Collective irrigation schemes performed notoriously bad on water delivery. Deliveries were untimely or insufficient, resulting in disappointing yields. Meanwhile, in many of these schemes, irrigation efficiencies were as low as 30 % (Burt and Styles, 1999; Kirpich *et al.*, 1999). Getting enough water to the crop on time while improving irrigation efficiency is a vital part of the answer to the irrigation challenge (Gleick, 2003; Rijsberman, 2006). In a first response, irrigation infrastructure was rehabilitated and/or modernized in order to facilitate the operation of the system and to make water delivery more flexible (Diemer and Huibers, 1996). Even though the rehabilitation has generally improved the irrigation efficiency, and might even be a necessary condition (Horst, 1999; Plusquellec, 2002a), experience has shown that it is not sufficient to focus on infrastructure only (Saleth, 2006). Attention of donors and practitioners has therefore shifted to management aspects (Kirpich *et al.*, 1999; Gleick, 2003). Under the impulse of studies on indigenous irrigation schemes, and common-pool resources management in general, it became gradually accepted that farmers can be effective managers (Ostrom, 1994a; Larson and Ribot, 2004; Agrawal and Gupta, 2005). The underlying assumption was that having the greatest stake in a good performance of water management, farmers themselves would invest more in water management than government officials did (Svendsen and Meinzen-Dick, 1997).

Farmers' role in water management was thus strongly enlarged through IMT (i) by shifting from supply-driven to demand-driven water delivery and (ii) by assigning them the responsibilities on operation and maintenance of (part of the) irrigation scheme (Kijne, 2001; Latif and Pomee, 2003). As such, farmers became managers and had to look beyond their plot to coordinate water supply with their neighbors, and even beyond the irrigation scheme, to share water with upstream and downstream users.

Even though farmers do find a timely and sufficient water delivery important, they were not necessarily demanding responsibility. On the contrary, IMT has generally been imposed on them (Jamin *et al.*, 2005). Hence, it is not self-evident that they are willing and able to assume responsibility beyond the borders of their plot (Le Gal *et al.*, 2001; Meinzen-Dick *et al.*, 2002; Moustafa, 2004). Nevertheless, farmers' participation in irrigation management is here to stay (Saleth, 2006). Furthermore, a supplementary rehabilitation or modernization of irrigation infrastructure geared to farmers' water management is unrealistic due to the high investment costs. The goal of this dissertation is therefore to investigate how under given constraints, the prospects of farmers' water management can be enhanced in the future.

Chapter 1
Enhancing the prospects of farmers' water management

1.1 Problem setting and objectives

Even though farmers' water management in irrigation schemes is put forward as the better alternative for management by the government, Irrigation Management Transfer (IMT) was never expected to be a simple process. Scholars and practitioners have pointed out several pre-conditions for success. First, it should be *carefully planned and prepared, with all relevant stakeholders being involved* in order to ensure their support (Vermillion and Sagardoy, 1999). Second, it requires an *appropriate legal and institutional framework*, taking into account local institutions and sources of leadership (Ostrom, 1993; Meinzen-Dick and Reidinger, 1995). In particular, water rights should be clearly defined, and responsibility should go hand in hand with accountability (Ribot, 1996). Insufficient clarification at this level can create insecurity and perverse incentive structures thwarting the goals of IMT (Vermillion, 1997). Third, *the necessary social capital*[1] *should be in place*, so that farmers can engage in collective action to achieve common goals (Ostrom, 1994b; Meinzen-Dick *et al.*, 2002). Indeed, a collective irrigation scheme is considered as a man-made common-pool resource[2]. Individual farmers have therefore an incentive to extract more water and invest less in maintenance than is optimal at the collective level (Tang, 1992). Collective action, i.e. certain rules, activities or the coordination of activities that promote the collective interest

[1] Social capital consists of relations of trust between people, reciprocity, common norms and social organization such as networks that facilitate cooperation and coordination for mutual benefit (Pretty, 2003).
[2] In common-pool resources, consumption by one person reduces the amount available to others while it is costly to prevent someone from using it. Furthermore, the benefits of investments dissipate to all users, which creates incentives for free riding (Ostrom, 2003). In the case of collective irrigation schemes, both the water and infrastructure are common-pool resources.

(Poteete and Ostrom, 2004), is needed to overcome this problem. Last, farmers should possess the *necessary knowledge and understanding of the management tasks* transferred to them (Le Gal *et al.*, 2001; De Nys, 2004). Indeed, in order to make the right strategic decisions, they need to know the alternative management options and their consequences. This is often too complex for common sense to do the job (Baland and Platteau, 1997).

The pre-conditions for success are well described in theory, but in practice they are either not applied as they should, or do not work as expected. Consequently, IMT does not always deliver the desired results, in particular in African irrigation schemes (Shah *et al.*, 2002; Jamin *et al.*, 2005). In particular, performance of water management remains unsatisfactory. Indeed, insufficient and/or inefficient water deliveries jeopardize a further expansion of the irrigated sector necessary to feed the growing population. The lack of fit between theory and practice of IMT often relates to an insufficient understanding of how these irrigation schemes actually work (Letsoalo and Van Averbeke, 2006). There is a fascinating paradox in this statement. Indeed, most of the surface irrigation schemes built in the 20th century -especially those in regions without existing indigenous irrigation- are designed and constructed by western experts, using hydraulic and agronomic principles developed by western scientists. Sure it is known how these schemes function? The big unknown, however, is how the local management and farmers appropriated and possibly adapted infrastructure and management procedures (Plusquellec, 2002a). This depends largely on their perceptions and attitude vis-à-vis the water resource and infrastructure and their mutual relations, which often differ largely from the view of the designers. Designs furthermore rely on a series of assumptions, such as numbers and qualifications of staff operating infrastructure and farmers' practices. These assumptions often do not correspond with reality, which in addition is not static, but likely to evolve over time (Gowing, 1999; De Nys, 2004).

Furthermore, the need for training of farmers on water management aspects is often underestimated because of the implicit assumption that local knowledge, based on daily experience, is adequate. Farmers in government-funded irrigation schemes however commonly originate from rain fed agriculture and did not bring a culture of hydraulics with them. Next, upon arrival in the irrigation scheme, a central management monopolized all decision-making on water management so that farmers have no experience to rely on at the moment of IMT (Shah *et al.*, 2002). In addition, past experiences do not always prepare farmers well for the challenge of water scarcity that looms over many irrigation schemes.

In order to help farmers to become good managers, actual problems with farmers' water management should be understood so that solutions can be proposed. This dissertation therefore takes up two challenges, which are tackled for the case of the Office du Niger irrigation scheme. First, it aims to develop an analytical framework for acquiring a thorough comprehension of farmers' water management. Using this framework, the process of IMT and resulting farmers' water management are scrutinized for their strengths and weaknesses, opportunities and strengths. Furthermore, the dissertation explores the physical, agronomic, economic, socio-cultural and institutional constraints that shape water management and its potential for improvement. After several rounds of reforms, farmers are still trying to adapt to the new reality after IMT. Therefore, rather than propose new reforms to alleviate them, the goal is to verify how performance of water management can be improved within the given constraints. Broadly speaking, there are two options. Either rules and procedures are adapted to actual farmers' practices, or farmers adapt their practices to existing rules and procedures. In this dissertation, both options will be explored.

With farmers participating in water management, they should be able to make informed decisions. The second challenge is therefore to show how the acquired knowledge can be translated into guidelines and tools to support strategic and day-to-day decision-making on water management. This challenge is not limited to theoretical reflections, but is tested in practice by developing examples of such tools.

By attacking these two challenges, this research hopes to contribute to farmers' successful transformation into managers in the Office du Niger, and collective irrigation schemes in general. Indeed, throughout this dissertation, it will be verified whether the insights gained can be extrapolated to other schemes. Such an extrapolation should be possible at three levels: First, the research approach as a whole, and in particular the analytical framework, is meant to be applicable (if not replicable) in other situations. Next, several of the conclusions and recommendations drawn from the analysis could be relevant for other cases. Finally, the major principles of the design of tools and guidelines should apply to other collective irrigation schemes.

1.2 Research approach

1.2.1 Justification of a case study and the selected case

When the goal of a research is to understand the lack of fit between theory and practice, it should take place in a real-life context. A case study then becomes the logical choice (Musch, 2001). Focusing on a single case furthermore allows entering in the full complexity of the selected case, which would not be possible if time was to be divided over multiple cases. However, in order to be able to generalize the findings, it is important that the selected case is sufficiently representative. The Office du Niger irrigation scheme in Mali is an interesting case, as it provides a classic example of the current trend of IMT in government-built, centrally managed irrigation schemes (Stemerding *et al.*, 2002). One of the major irrigation schemes of West Africa, it is of strategic importance for international donors and has been a showcase for IMT. Furthermore, it harbors a considerable diversity in hydraulic infrastructure, which favors generalization. A peculiarity that sets the Office du Niger apart from other irrigation schemes is that because of its physical layout, pumping costs can be avoided and water is unusually cheap (see Chapter 2). In many irrigation schemes, as in the Office du Niger, farmers do not pay for their actual consumption, so that incentives at farmer level are similar. In addition, the opportunity cost of water in the Office du Niger is quickly rising, making water as valuable as elsewhere.

1.2.2 The analytical framework

Stakeholder analysis

IMT, with its implicit water conservation agenda, was (and sometimes still is) based on the naïve paradigm that water conservation is good for all stakeholders. Often, it was not realized that some conservation practices are neutral or can even go against the interests of participating farmers, who generally carry the largest burden of conservation activities but not necessarily reap the rewards. Furthermore, the conservation practices might be beyond the farmers' capacity. As a consequence, not all transfer programs have led to the desired results (Cleaver, 1999; Moustafa, 2004; Blaikie, 2006). In fact, the different stakeholders (farmers, central management, government, donors, …) take decisions based on their own objectives and a mental model of how actions, (i.e. water management practices in the context of irrigation), will influence results (van Noordwijk *et al.*, 2002) (Figure 1.1). Performance is then defined as the divergence between objectives and actual results (Dia, 1993).

The stakeholders are diverse and can have competing objectives, often because they operate at different scales in time and space. In addition, mental models are determined by certain assumptions, knowledge or perceptions. Different stakeholders therefore define problems in different ways and policies often fail as they are implemented to address certain problems that are not relevant in the view of farmers (Adams *et al.*, 2003). A first step in the analytical framework is therefore to explore the objectives and mental models of the different stakeholders in a stakeholder analysis. Only if we understand these, we can distinguish whether sub-optimal performance linked to sub-optimal farmers' water management is a question of capability or incentives.

Evaluation of organization and performance of farmers' water management

Stakeholders' mental models of how actions influence results might not only conflict with each other, they might also deviate from reality. In particular, mental models might be prejudiced by an idealistic view on how management should be. In the course of time, stakeholders can learn and adjust their mental models based on their increasing experience on the actual results of actions in the real world. The relation between actions and results however is not always directly visible, which obstructs learning cycles. Discerning this relation clearly might require a more distant and neutral perspective, which a scientific approach should have. In order to set the problem statement right, it is therefore necessary to analyze the impact of different management practices on performance in the real world through a field study (Figure 1.1). Usually, a variety of practices is in use, as farmers attach varying importance to water conservation and the available social capital in farmer groups differs. Rather than test new practices, the approach adopted by this research is therefore to make stock of the diversity of existing practices and assess their impact on performance.

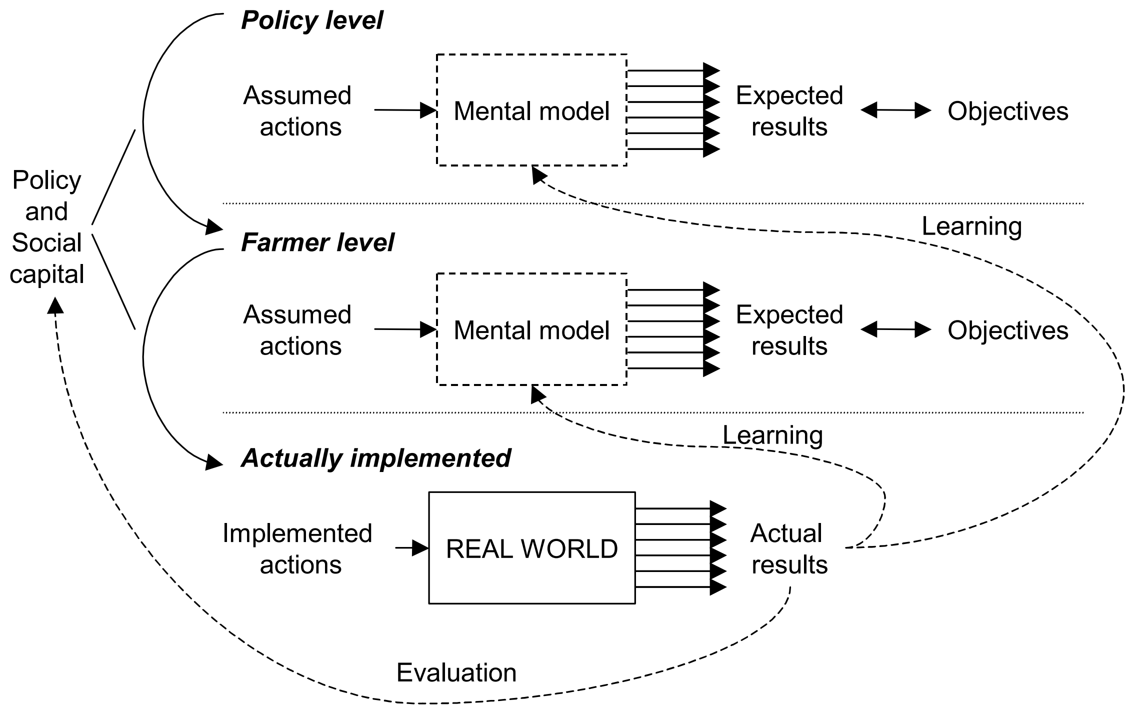


Figure 1.1 Theoretical framework of natural resource management driven by manager's objectives and mental models (adapted from van Noordwijk *et al.*, 2002)

The evaluation consists in the following steps: Firstly, *actual performance should be assessed*. What is considered as “good” or “bad” performance of water management depends heavily on stakeholders’ objectives, which have been assessed in the stakeholders analysis (Dia, 1993). In order to measure performance from these different points of view, performance indicators should be constructed for each of them. Secondly, *current management practices have to be identified and understood*. In collective irrigation schemes, water allocation and consumption, maintenance and cropping calendars are typical water management aspects that might benefit from collective action. Still, despite obvious benefits, collective action is not guaranteed to take place, as designing and enforcing rules demands time and effort and may face social or other constraints (Olson, 1973; Le Gal and Papy, 1998). It is therefore important to gain insights on the diversity of current water management practices, with in particular the prevalence and strength of collective action and mechanisms that monitor and enforce it. Finally, *possible connections between management and performance should be explored*. For this last step, quantitative analysis has a valuable advantage over a qualitative approach because it allows distinguishing which relation is important and which is not. Even though there is a fast build-up of knowledge on how local users individually and collectively engage in natural resources management, studies on farmers’ water management in collective irrigation schemes after IMT are still quite rare (e.g. Dayton-Johnson, 1999; Sokile and van Koppen, 2004; Marothia, 2005). Furthermore, most studies on natural resources management focus on social performance, investigating whether user groups succeed in establishing collective action. Quantifying the impact of various individual and collective management strategies on technical performance is still underdeveloped and is an innovative aspect in this dissertation.

Analyzing the social forces behind water management

This research follows Vincent’s (2003) assertion that social forces, more than scientific principles, shape water management practices. These social forces comprise in the first place the socio-economic factors determining the trade-off of expected costs and benefits of collective action. In a wider sense, they also include the social relations among users, their attitude towards water and the infrastructure and the legitimacy of formal and informal leaders. The current trend of seeking “social fixes” to water management problems, such as IMT and the setting up of WUAs, tries to set the social context right. Most often, they are imposed in a top-down manner following principles such as democratic representation that are thought to be universal conditions for a successful organization (Abdelhadi *et al.*, 2004; N'Khoma and Mulwafu, 2004; Jamin *et al.*, 2005). However, at the same time, the way these "social fixes" turn out in practice is subject to the same social context, thoroughly impregnated in culture and its historical path (Cleaver, 1999; Mosse, 1999; Steins and Edwards, 1999). In the analysis of the social forces behind water management, two points stand out. First, informal institutions and leaders often continue to take an important part in decision-making after WUAs were put into place (Ribot, 1996; Wester *et al.*, 2003; Thakadu, 2005). It is therefore important to find out how decisions are really taken in order to understand current management practices. Second, in order to create the right conditions for collective action and recognize possible limitations, the influence of the socio-economic determinants has to be understood.

Box 1 Approach to field work

The research was set up as "research for development". This not only reflects its goals of supporting farmers' water management to enhance sustainability and expansion of irrigation activities in the study area. It also determines the research approach, which implied a close cooperation with farmers, water guards and the central management. As such, they participated in many of the research activities and several occasions were created to present and discuss results. A local research center experienced in training and extension for farmers in the irrigation scheme accommodated the research project. This created a necessary degree of independence from the central management, and greatly favored interaction with farmers. The field study lasted three years and covered several researches using separate samples to ensure the independence of the results. In irrigation schemes, systematic data on water management (e.g. flow rates or water levels in canals) are often scarce or inexistent, which makes an elaborate data collection necessary. This scarcity of data is furthermore reflected in the scarcity of measurement structures, so that alternative sources of information must be explored. In addition, some questions demand a more in-depth understanding, to which systematic data series do not necessarily provide an answer (Goering and Streiner, 1996). Consequently, quantitative as well as qualitative and participative research methods were used, depending on the questions to be answered. Local researchers, Office du Niger staff and farmers contributed to the data collection, which allowed boosting the amount of available data, enhanced their participation in the research process and generated additional viewpoints and insights. Research activities furthermore included participation in workshops on ongoing projects on water management and meetings with Office du Niger staff, NGOs and international donors that designed the projects. Existing scientific and project literature complemented data collection. During the three years of fieldwork, periods of data collection were alternated with periods of reflection, which allowed digging deeper into certain subjects after several iterations.

1.2.3 Developing tools for improved farmers' water management

In this dissertation, it is substantiated that farmers need training and decision-support on water management in order to cope successfully with the tasks transferred to them by IMT. The dissertation furthermore provides examples of tools for training and decision-support. These tools have not yet been fully implemented and evaluated and therefore should not be seen as ready-to-use research results. The objective is rather to demonstrate through realistic examples what such tools need to be. Practically, the question to ask is: what do they need to tell, how and to whom. In other words, in order to be both efficient and effective, information needs to be selected that responds best to needs. Next, when the tools deal with certain relations, variable and invariable parameters need to be chosen in function of constraints faced by farmers that determine which of the parameters they can influence. Last, the target audience needs to be determined, so that both those most in need of information are included, as well as possible opinion leaders who might foster the adoption of the tools. The necessary knowledge to answer these questions follows from the analytical part of this study.

1.3 Outline of the dissertation

This dissertation is structured in different parts that each contains several chapters. Figure 1.2 presents a schematic overview of the logical coherence between chapters 2 to 10.

The Introduction part contains two chapters:

- Chapter 1 outlined the problem setting of farmers' water management after IMT and explained the research approach developed throughout the research.
- Chapter 2 explains the context of the Office du Niger case. It describes the physical, institutional and social environment. The chapter also presents the results of the stakeholder analysis of water management in the irrigation scheme, which is the starting point for further analysis.

Part I contains the evaluation of organization and performance of farmers' water management based on the results of a field study. This part is divided into four chapters that each correspond to one or more steps of the evaluation as described in the analytical framework:

- Chapter 3 assesses the hydraulic performance at the tertiary canal level. It therefore uses indicators for efficiency, adequacy, dependability and equity of water delivery. Furthermore, the evolution of performance is examined in the light of the interventions in the irrigation scheme and farmers' water management strategies.

- Chapter 4 aims to identify and understand current management practices at the tertiary block level. In particular, it studies how farmers resolve collective action problems concerning maintenance of irrigation canals and water allocation through devising, monitoring and enforcing rules. It investigates the diversity and effectiveness of these rules and looks at the impediments to successful organization of water management.
- Chapter 5 explores the relation between water management practices and irrigation performance using a quantitative approach. Performance indicators are constructed, taking into account the different stakeholders' perspectives. Combining the results from the field study and from the stakeholder analysis, the chapter sets out some suggestions for improving water management in the face of the expansion of the irrigated surface.
- Chapter 6 investigates the relation between water management practices and drainage. In particular, it looks at drainage problems at harvest, which are widespread in the irrigation scheme. It estimates the impact of various measures to alleviate these drainage problems.

Part II corresponds to the analysis of the social forces behind water management. Specifically, it aims to get insights in social relations among water users, their attitude towards the water resource and infrastructure and the legitimacy of formal and informal leaders, which all shape farmers' water management. This part contains two chapters:

- Chapter 7 studies decision-making on water management at the village level. Specifically, it compares formal Water Users Associations to informal centers of decision-making on water management through an institutional analysis. It evaluates their effectiveness and flaws within a historical perspective to gain an understanding on how institutional change can be more successfully implemented.
- Chapter 8 investigates farmers' motivation for collective action on water management. By looking at the socio-economic determinants of motivation, the prospects for collective action given the present dynamics in the irrigation scheme are assessed. The results of the analysis lead to policy recommendations to enhance the prospects for collective action.

Part III presents tools for training and decision support at farmers' level. Rather then presenting new research results, this part aims to demonstrate how the insights gained through Part I and II can be translated for this purpose. It includes two chapters that each present a different tool:

- Chapter 9 presents an example of training material (extension posters and a trainers' manual) that is expected to help farmers in understanding the impact of individual management practices and collective action on performance.

- Chapter 10 presents a simulation model of water management at the tertiary level. It consists in an analytical tool that can be used to find the optimal mix of water management practices that increase irrigation efficiency while preserving farmers' interests. The chapter translates the results of simulations into practical guidelines for farmers.

The final part of the dissertation contains the conclusions and perspectives. It comments on the research process in the Office du Niger case study. Next, it evaluates the relevance of the research results for other irrigation schemes. Finally, it discusses the interest of the research approach and opens some perspectives for further research or follow-up of results.

The dissertation furthermore contains several boxes, presenting briefly subjects related to farmers' water management in the Office du Niger irrigation scheme but which are not fully treated in the body of this dissertation. They aim to complete the analysis, show the complexity of the case under study or put the subject of water management in perspective.

CONTEXT OF THE OFFICE DU NIGER CASE STUDY

Chapter 2: Present the problem setting of the selected case and the physical, agronomic, institutional and social context of farmers' water management

STAKEHOLDER ANALYSIS

Chapter 2: Explore stakeholders' objectives and mental models of how actions will influence results

ANALYSIS OF ORGANIZATION AND PERFORMANCE OF FARMERS' WATER MANAGEMENT

Chapter 3: Assess hydraulic performance
Chapter 4: Identify current management practices
Chapter 5: Explore the relation between water management practices and irrigation performance
Chapter 6: Explore the relation between water management practices and drainage problems

ANALYSIS OF SOCIAL FORCES BEHIND WATER MANAGEMENT

Chapter 7: Map decision-making on water management at the village level
Chapter 8: Investigate farmers' motivation for collective action on water management

Translation of research results

DEVELOPMENT OF TOOLS FOR DECISION SUPPORT

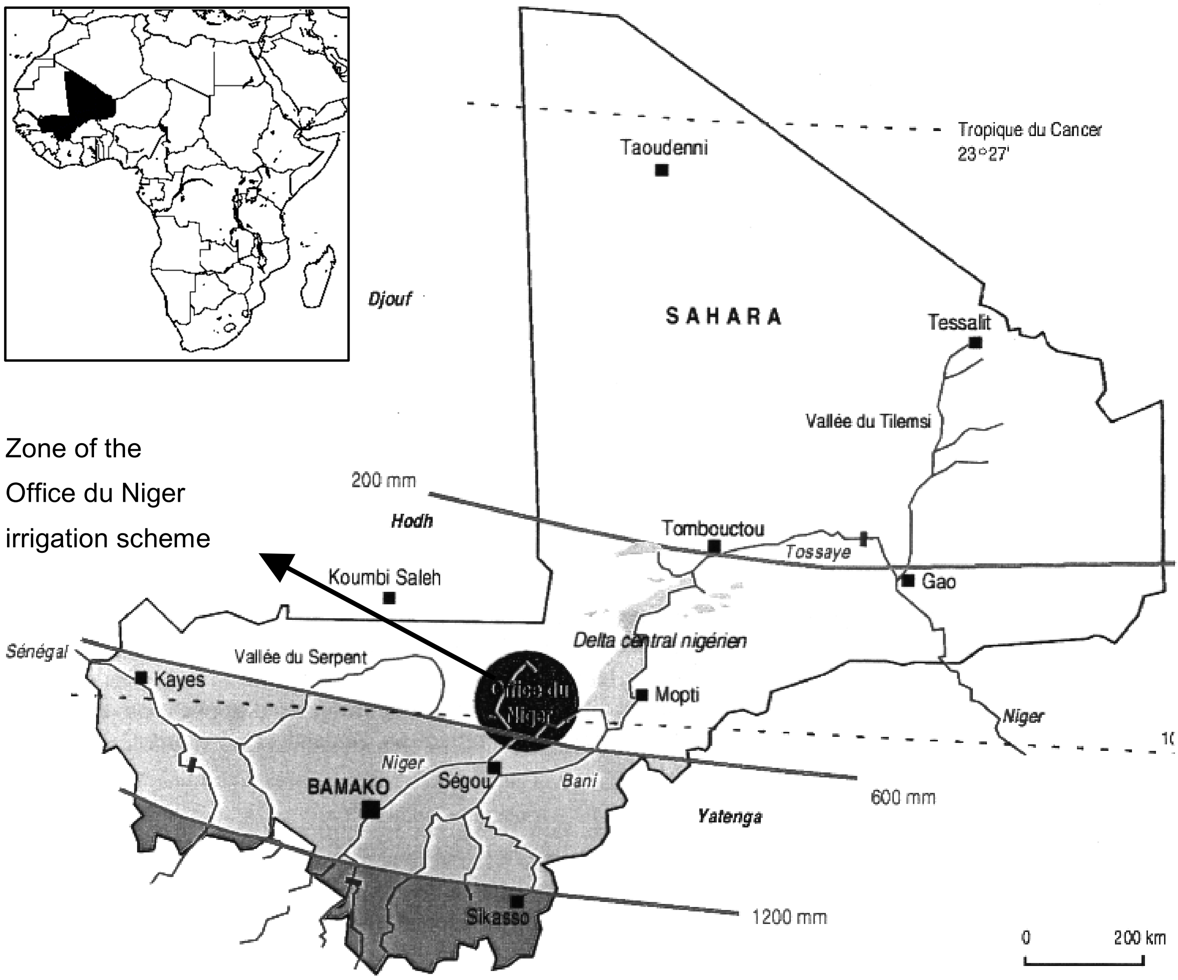
Chapter 9: Develop training material to help farmers understand the impact of various water management practices on performance
Chapter 10: Develop a simulation model of water management that helps determine the optimal mix of water management practices to face present and future challenges

Figure 1.2 Schematic overview of the logical coherence of chapters 2 to 10

Chapter 2
Presenting the case study: The Office du Niger irrigation scheme in Mali

2.1 Problem setting

With its 80,000 ha of irrigated land, the Office du Niger is one of the largest irrigation schemes of West Africa. It is situated in the Ségou region in Mali (Map 2.1 and 2.2). At present, it is of vital importance for national food security in Mali, providing approximately 465,000 tons of paddy each year or 40 % of the national production. As such, the Office du Niger contributes significantly to the self-sufficiency of the country in rice, which is currently at about 90 % (Chohin-Kuper *et al.*, 2002). The current achievements contrast sharply with the situation at the end of the 1970s, when the notoriously low agronomic and financial performance nearly obliterated the Office du Niger. Created in the 1920s by the French colonial power, the central management tightly ran the irrigation scheme until it was pressed into reforms. By the end of the 1970s, the Malian government sought the financial support of international donors for a physical rehabilitation of the Office du Niger to improve the conditions for crop production. The latter were prepared to get involved on the condition of economic and institutional reforms. The reform process started in the early 1980s and completed in 1994. It led to the liberalization of crop production and marketing and the reduction of the central management in favor of more farmer autonomy and participation (Bolding, 2004). As such, the competencies of the central management were reduced to operation and maintenance and a partial Irrigation Management Transfer (IMT) to farmers was carried out (Aw and Diemer, 2005). This transfer has been most complete at the tertiary canal level, where water management is entirely left to farmers (Touré *et al.*, 1997). The tertiary level will therefore be the focus of the case study.



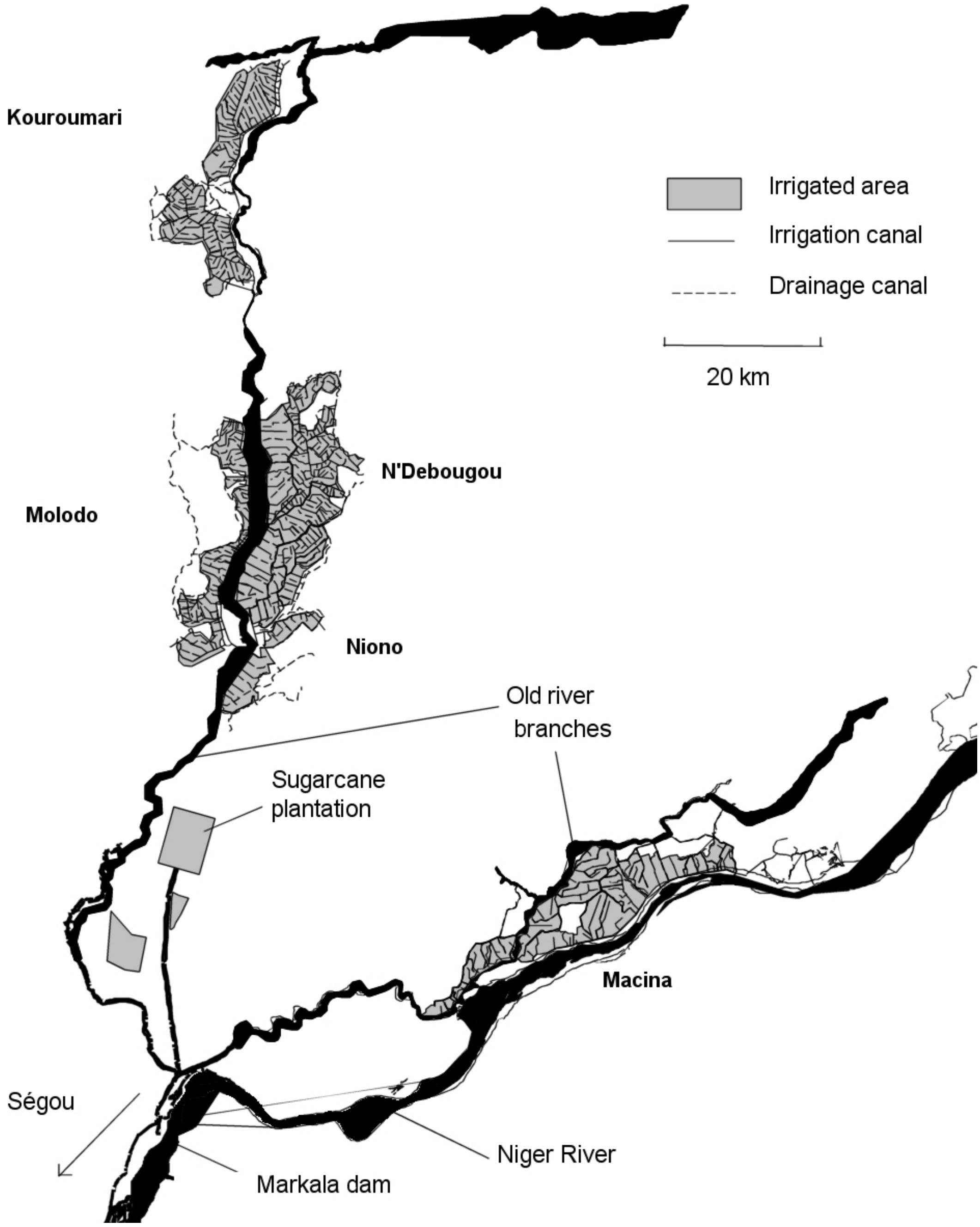
Map 2.1 Location of the Office du Niger irrigation scheme

The economic success of the intervention package is beyond doubt. Yields have risen from barely 1.5 t/ha to about 6 t/ha (Couture *et al.*, 2002), resulting in significant increase of farmers' income and economic activity in the region (Mariko *et al.*, 2000). The difference between before and after the reforms were in fact so impressive that the Office du Niger irrigation scheme became the textbook example of how reforms should be successfully conducted (see Box 2). These achievements have created ambitions for further development of the area (Coulibaly and Sangaré, 2003; AFD, 2004). With an irrigable surface of about 1,000,000 ha, a huge agronomic potential remains untapped. An expansion of the irrigation scheme would provide a more stable livelihood for many rural dwellers that now depend on the vagaries of rain fed agriculture. Waiting lines for obtaining a plot in the area are lengthy, and many communities living in the fringe of the irrigation scheme lobby for the construction of irrigation infrastructure on their territory. Furthermore, thanks to the fact that no pumping costs are involved in conducting water to the irrigation scheme, and that manual labor and animal traction are the main production factors, the rice produced in the Office du Niger is highly competitive nationally as well as internationally. The expansion would therefore be beneficial for the Malian economy, generating further economic development and making the country less reliant on food imports. Mali is currently among the ten poorest countries of the world, with almost three quarters of people living below the poverty line of one dollar a day (UNDP, 2006). Agriculture accounts for more than a third of GDP and around 80 % of the working population and therefore remains crucial for human as well as economic development (Toulmin and Guèye, 2003).

Box 2 The Office du Niger in a box

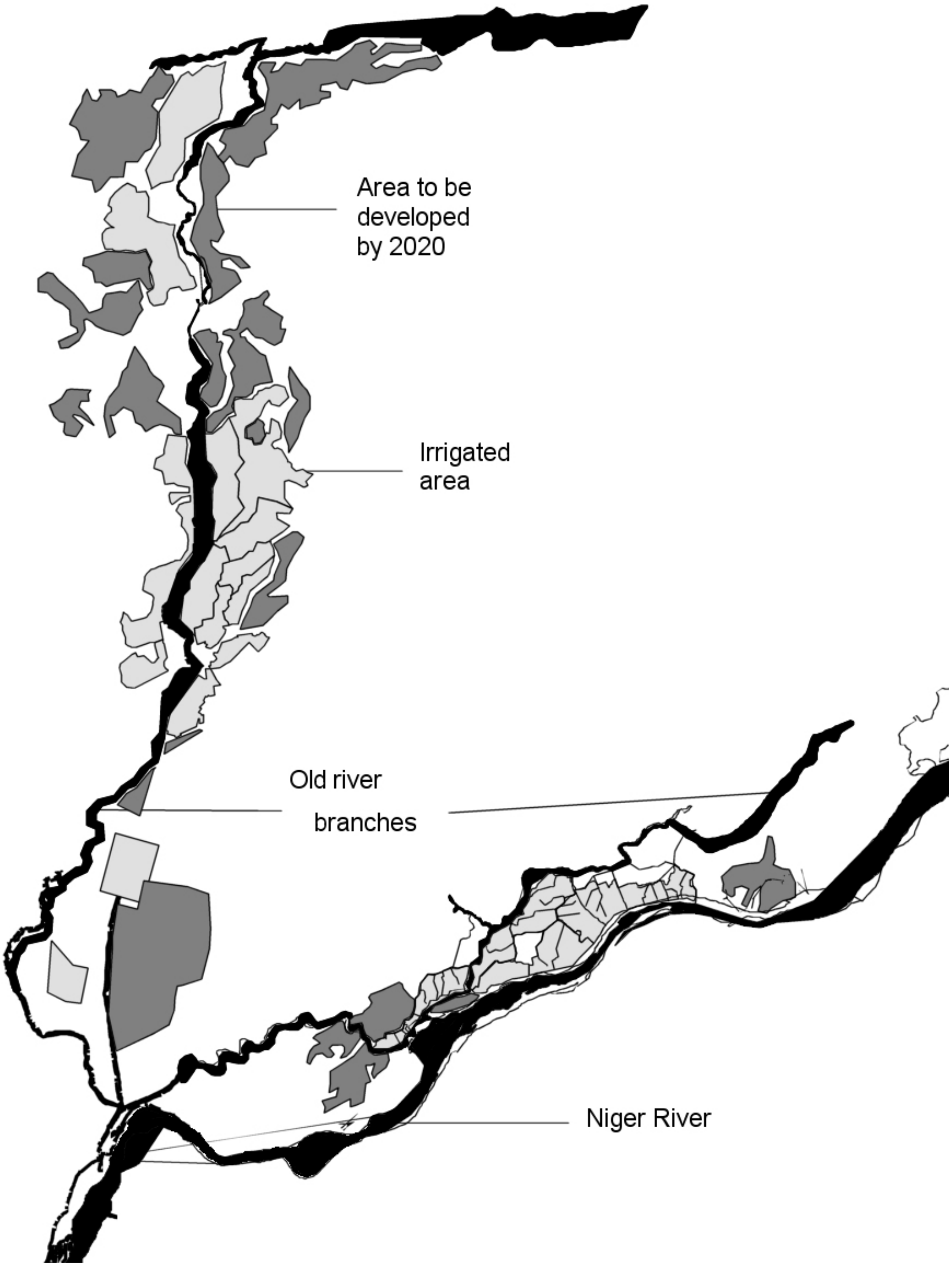
In recent years, many reports have featured the successful reforms of the Office du Niger as a textbook example in one of its boxes. Most of them measure the success by the increase in rice production from 1.5 t/ha before reforms to 6 t/ha afterwards. Even though this is perhaps an optimistic estimate, the result is still impressive. A small survey learns that the Office du Niger story is used to illustrate different theories to explain its success. For some authors, the rise in yields is basically the result of technological innovations. Modernization of irrigation infrastructure and laser leveling of land made a better water control possible, which in turn allowed the adoption of improved rice varieties and techniques such as transplanting (Plusquellec, 2002a; IPTRID, 2003; World Bank, 2006; not dated). For others, it was the liberalization of agricultural markets and the devaluation of the CFA Franc that provided the necessary incentives for increased rice production (Gabre-Madhin and Haggblad, 2004). A third point of view is that disengagement of the state, more farmer autonomy and farmer participation in decision-making has provided the right conditions for yield increase (Johnson *et al.*, 2004; Unesco, 2006). Finally, according to a last group, only the mix of all of these made the success of the Office du Niger possible (Davis and Hirji, 2003; Darghouth, 2005). This vision is supported by a thorough review of the reform process by Aw and Diemer (2005). They show that the reforms were not the result of a ready-made package with the right ingredients. The reforms rather consisted in a series of small steps that followed from tough negotiations between the Malian government and international donors. The latter formed a united front on some occasions so that fundamental changes could be pushed through. They engaged in a fierce competition on others moments, so that the Office du Niger benefited from complementary views and was able to build on the most successful ones.

The Office du Niger has already embarked on an impressive expansion program, aiming to reach 200,000 ha by 2020 (CDP, 2004). The head works of the irrigation scheme are already used at full capacity to supply water to the actual 80,000 ha of irrigated land. Since extending them would require costly investments, the expansion should be realized without a significant increase in water consumption. This is possible if overall irrigation efficiency, currently no more than 25 %, is substantially improved. Another reason to focus on irrigation efficiency is



Map 2.2 Map of the Office du Niger irrigation scheme with indication of the five administrative zones

that national as well as international competition for water increases. The irrigation scheme withdraws its water from the Niger River, which crosses five countries. As the population of these countries grows and their economies develop, water demand from households, agriculture and industry rises. Annually, the Office du Niger withdraws around 10 % of the Niger River's water. Most of the water lost in the irrigation scheme cannot be used downstream as it flows to depression in the desert where it percolates or evaporates. Being such a significant consumer, large-scale water losses cannot be justified. Furthermore, increasing irrigation efficiency is important to reduce the recurrent drainage problems in the



Map 2.3 Planned expansion of the Office du Niger irrigation scheme

area. These might negatively influence the quantity and quality of rice production and bring along the risk of soil degradation through salinisation and alkalinization (N'Diaye, 1987; Dicko, 2005). Drainage problems furthermore foster water-borne diseases such as malaria and schistosomiasis (Klinkenberg *et al.*, 2002). Besides the human suffering, these diseases might produce an economic cost because of the loss of labor that even goes beyond the agronomic losses (Audibert and Etard, 1998).

Ouvry and Marlet (1999) have shown that the tertiary level takes up an important share of water losses and present the greatest potential for increasing irrigation efficiency. Evaporation and percolation losses occur in the abandoned river channels, but they are expected to remain constant in absolute terms when the conveyed water volumes increase. Next, few conveyance losses occur in the primary and secondary canals, but efficiency is low at the tertiary level. The central management and international donors blame the water losses on poor farmers' water management. They set up several projects to remedy this situation, introducing new institutions, procedures and regulations for water management at the tertiary level, albeit with limited success. Farmers on the other hand, appreciate their independence, but feel they lack the necessary knowledge and skills to be in full control of water management (Colin and Petit, 2007). In this context, the further success of the irrigation scheme will depend on the strengthening of farmers' water management, which is studied in this dissertation.

2.2 Description of the study area

2.2.1 The physical environment

The zone of the Office du Niger (14°18'N 5°59'W) has a semi-arid climate. Yearly rainfall varies from 300 to 600 mm and is concentrated in the months from July to September (Figure 2.1 and Figure 2.2). Reference evapotranspiration amounts to about 2,500 mm a year and exceeds rainfall in all months except August (Hendrickx *et al.*, 1986). Yearly rainfall increases from north to south in the study area (Boeckx, 2004). Soils are predominantly *Fluvisols* and *Vertic Cambisols* with a clayey texture (Haefele *et al.*, 2003). The water table, initially at 40 m deep, is at 1 to 2 m deep during the dry season and reaches the ground level during the rainy season (Dicko, 2005).

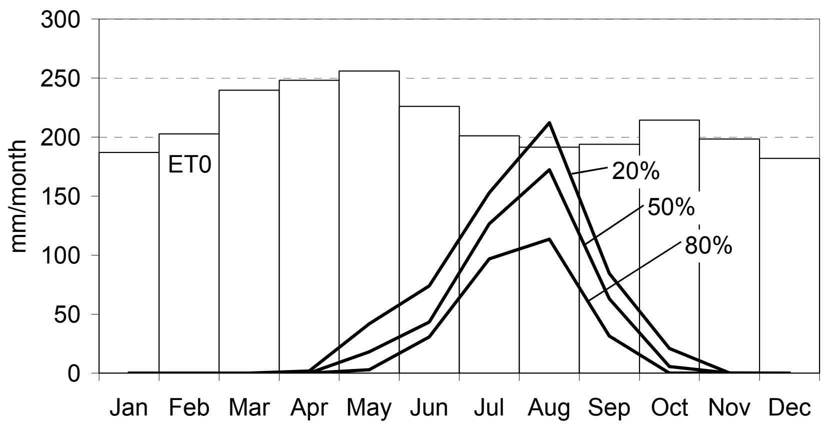


Figure 2.1 Mean monthly reference evapotranspiration (ET0) and monthly rainfall with a probability of exceedance of 20, 50 and 80 % for Niono

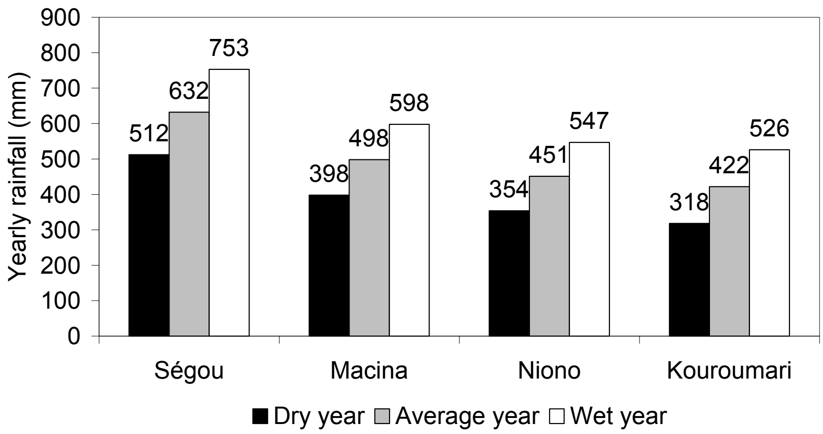


Figure 2.2 Yearly rainfall with a probability of exceedance of 20, 50 and 80 % at different locations in the study area (Source: Boeckx, 2004)

The entire irrigation scheme is dominated by a dam on the Niger River, from which it withdraws water by gravity. Water is first diverted to two abandoned river branches (called *fala*) that are put back into use (Map 2.2). The dam, abandoned river branches, their intakes and control structures correspond to the head works of the irrigation scheme. The river branches then supply a hierarchic irrigation network consisting of primary (*distributeur*), secondary (*partiteur*) and tertiary canals (*arroseur*), all of them unlined. Field canals connect the tertiary canals with tertiary drains (Figure 2.3). In this study, the tertiary level is defined as the aggregate of hydraulic structures, canals and fields in between the intake of the tertiary canal and the outlet of the tertiary drain. The water enters the system through the intake of the tertiary canal. On the tertiary canals, five to twenty field canals are connected trough field intakes. Each field canal serves a field of about two hectares. The aggregate of fields along a tertiary canal is called tertiary block.

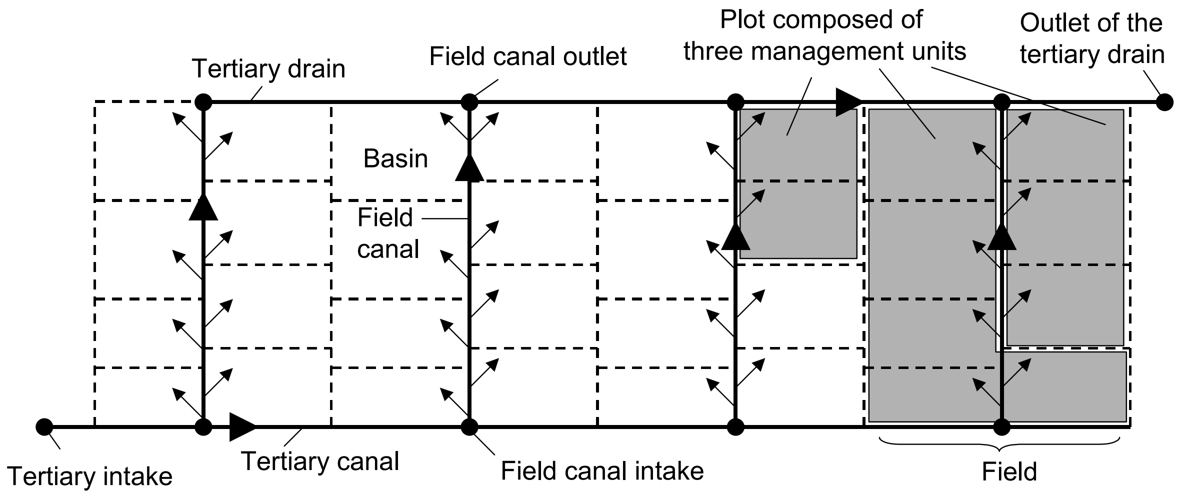


Figure 2.3 Layout of a tertiary block

A field contains different basins into which water flows through breaches in the dikes that enclose them. The same field canals evacuate water towards the drainage network. Farmers' plots consist of several basins, but do not necessarily follow the boundaries of the fields. One plot can comprise basins in several fields, and one field can be shared by two or three farmers. A farmers' unit of decision-making on the crop, planting date, irrigation and drainage is an aggregate of several basins of his plot within the same field. Such a unit of decision-making or management unit, will thus get a uniform treatment.

Rehabilitation of the irrigation scheme makes steady progress and by now has reached more than half of the irrigated surface. The various donors who financed the rehabilitation have followed each their own philosophy with respect to the construction and operation of the hydraulic infrastructure, resulting in different types of infrastructure with particular designs and dimensions of intakes, canals and basins. At the tertiary level, these types can be roughly divided in two groups (Table 2.1). The Retail-type (as the French project that first implemented it) uses baffle modules for the tertiary intakes. Thanks to the design of the baffles in the opening of the intake, the modules maintain a constant incoming flow for a wide range of upstream water level variations. The various modules of the intake each have a specific flow rate, so that the incoming flow is easy to control. The design flow rate is 1.8 to 2 l/s/ha at the tertiary intake. As the modules come in blocks of 30 l/s, the capacity of the intake can go up to 4.5 l/s/ha, depending on the surface to be served by the tertiary canal. As a rule, a lock secures the intake and only water guards can open or close the modules. In practice, the lock is often missing, or farmers have a copy of its key. The Retail-type furthermore has overflow structures at the level of every field canal intake that discharge in the field canal and then the tertiary drain to prevent damage to the banks of the tertiary canal when the water level is too high. The Arpon-type (as the Dutch project) uses semi-modular weirs as tertiary intakes that can be closed with a single sliding gate. The width of the weir is adapted to the irrigated surface of the tertiary block, so their capacity is always around 2 l/s/ha when the upstream water level is at its design level. Small variations in the upstream water level however cause large variations in the incoming flow rate. Tertiary canals of this type have only one overflow structure at its end that discharges directly into the secondary drain. Since the early 1990s, the Arpon type is no longer built (IOV, 1992). Finally, some areas have not yet been subject to rehabilitation and still have the original infrastructure with non-modular sliding gates at the intakes of the tertiary canals. Here, both the upstream and the downstream water level influence the incoming flow rate, which is therefore hard to control.

The original design did not feature field canals, but farmers often created them themselves. Otherwise, plots are irrigated and drained from basin to basin.

Tertiary canals are about 2 to 4 m wide and less than 1 m deep. This makes for a very large cross-section compared to volume of water they need to transport. Consequently, the hydraulic slope is quasi nil and field canal intakes are situated all at the same level, even though tertiary canals can be over 1,000 m long.

Table 2.1 Properties of the design and dimensions of intakes, canals and basins of the Retail and Arpon type of irrigation infrastructure

Type of infrastructure	Properties	Photo of the tertiary intake
Retail type	Baffle modules at the intake of tertiary canals; intake at the tertiary level locked; evacuation of excess water of the tertiary canal through overflow structures discharging in the field canals; 1 field canal per 2 ha; basins of 0.1 ha constructed by engineers and machine leveled	
Arpon type	Semi-modular sliding gates at the intake of tertiary canals; intake at the tertiary level not locked; evacuation of excess water of the tertiary canal directly to the drainage network through an overflow structure at the end of the canal; 1 field canal per 3 ha, additional field canals constructed by farmers; basins constructed and leveled by farmers	
Not rehabilitated	Non-modular sliding gates at the intake of tertiary canals; intake at the tertiary level not locked; no field canals, unless constructed by farmers	

The drainage network is structured analogous to the irrigation network. The tertiary drains are dimensioned at a capacity of 1.4 l/s/ha, which corresponds to the peak drainage requirement (Sogreah, 1987). Drainage water is conveyed by gravity from the tertiary drain to the secondary drain and finally to the collector drain, both with a capacity of about 0.5 l/s/ha (Sogreah, 1987). All fields and drainage canals discharging either directly or indirectly to the same collector drain constitute one drainage system. Given the flat area and the absence of hydraulic control structures, all drainage canals of a drainage system function as communicating vessels. Although the collector drains close to the Niger River discharge into the river, most collectors dump the drainage water in natural depressions where the water infiltrates and evaporates. At the borders of the irrigation scheme, drainage water is often used to irrigate illegal plots. In order to extract water by gravity, dams are sometimes constructed in the drainage canals (Van der Walle, 1982).

2.2.2 The crop

The principal crop is paddy rice (*Oryza sativa* L.) grown during the rainy season May to November). A second rice crop and vegetables are grown during the dry season on 10% to 20% of the total surface (see also Box 6). The irrigation scheme contains also a sugarcane plantation (3,000 ha) and some orchards (1,000 ha). This research focuses on rice cultivation during the rainy season, as it is by far the most important crop.

Water requirements for rice cultivation amount to 5 to 12 mm/day, depending on the atmospheric demand, rainfall and percolation losses. Variations between the different varieties are minimal. Consequently, differences in total water requirements mostly depend on the climate, soil type and the length of the growth cycle. In addition, for rice cultivation, some water is needed for land preparation and to maintain a water layer throughout the growing season. Even though research has pointed out that this water layer is not strictly necessary for rice cultivation (Bouman, 2001), it acts as a buffer to allow flexible spacing of irrigation events. Without this buffer, farmers would need to have a permanent access to water for irrigation, as even short periods of water deficit can cause large reductions in yield. The most sensitive periods are the late vegetative period and flowering. The water layer furthermore reduces weed growth and protects the crop against damage by rats and other ravagers.

In the process of the reforms of the Office du Niger irrigation scheme, improved rice varieties have been introduced. These are non-photosensitive, short stem varieties with a growth cycle of 120 to 145 days. The most commonly used varieties are BG 90-2 and Kogoni 91-1, also known as Gambiaka Suruni, which have a growth cycle of respectively 130 and 140 days and a yield potential of 10 t/ha. Their total seasonal water requirements amount to about 1,050 mm. Transplanting is the common practice for crop establishment (Haefele *et al.*, 2003). Rice is sown in seedbeds and transplanted after 30 days on average (Dicko, 2005). The season sets off at the end of May with the installation of seedbeds. Rice transplanting begins gradually by mid-June and continues until the end of September (Figure 2.4). The peak irrigation demand falls during the month of September, when over ninety percent of the cultivated surface is irrigated and the rainy season reaches its end. The first fields are harvested already by mid-September and harvesting continues until the end of December. Late rice (harvested in December) often suffers from low yields as the cool temperatures during flowering induce sterility. For the reasons mentioned above, a water layer is maintained from the moment of transplanting until about 10 days before harvest.

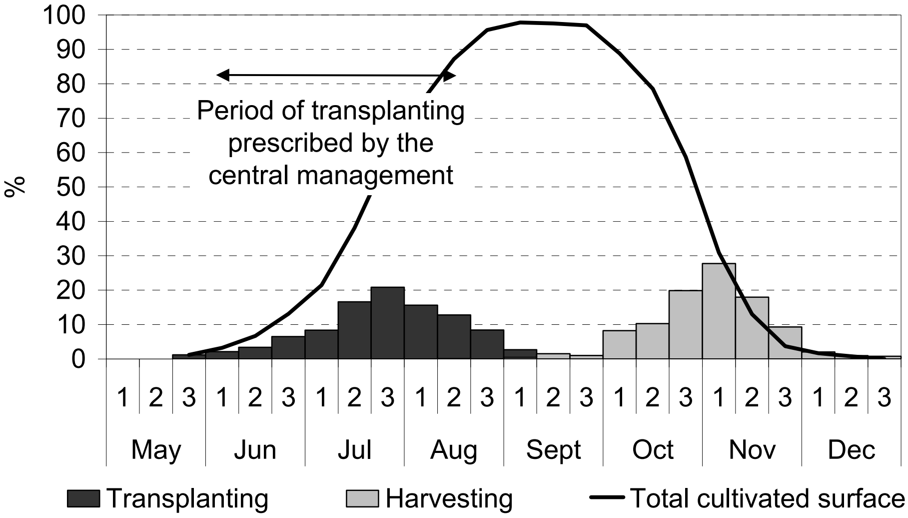


Figure 2.4 Evolution of transplanting, harvesting and the total cultivated surface during the main growing season (Source: survey data)

2.2.3 The institutional environment

Since the reforms, responsibilities have been clearly divided between the Malian state, farmers, and the central management of the irrigation scheme. They are renegotiated every three years between representatives from all involved parties and recorded in a "Contrat-Plan", or negotiated contract. The core responsibilities of the central management are water delivery and maintenance of the irrigation infrastructure. It is furthermore in charge of management of the territory and capacity building at farmers' level, including technical assistance, tasks that have been assigned to the Malian state, but are confined to the central management. It has its headquarters in the city of Ségou, but is decentralized in five administrative zones that each has a directorate implementing water and land management quite independently in their part of the irrigation scheme. Regarding water management, the headquarters are responsible for operating and maintaining the head works. For this, it receives funds from the Malian state. The primary and secondary canals are operated by the water guards of the directorates. The directorates are also responsible for maintenance of these canals. Farmers participate in the management and allocation of these funds through a so-called Joint Committee on Maintenance at Secondary Level, of which there is one for each administrative zone. Operation and maintenance of primary and secondary canals are paid for by farmers' water fees. Rates are non-volumetric, but linked to the type of crop, growing season, and land class. The most expensive class corresponds to rehabilitated land, where a full water service is guaranteed. Then follows not-rehabilitated land, and finally the so-called 'hors-casiers' that are irrigated through illegal outlets constructed by farmers. Fees are negotiated yearly between the Malian state, the central management and farmers. For the rice crop in the main growing season, they correspond to about 25 % of total production costs.

Finally, farmers are collectively responsible for water management at tertiary block level. Certain regulations stipulated in the negotiated contract limit farmers' liberty of action (Couture *et al.*, 2002). The regulations concern the obligation to maintain tertiary infrastructure, respect the prescribed cropping calendar (Figure 2.4) and cultural practices in line with intensification of rice production, limit water use, and practice double cropping on the plots destined for that purpose. Every tertiary block has a canal chief, who acts as an intermediary for passing on information between farmers and water guards and is supposed to organize and coordinate water management activities at the tertiary level. Lacking recognition by fellow farmers, the chief has often little substance. Since 2002, tertiary level WUAs are created on the initiative of international donors to formally organize farmers around water management and as such fill the power vacuum left by the implementation of IMT.

2.2.4 The social environment

Farmers live in villages nearby the downstream plots of one to three nearby secondary canals. The area being scarcely populated, most villages of the irrigation scheme were newly created starting from the 1920s, and populated through various waves of forced and voluntary immigration from different regions in Mali and Burkina Faso (van Beusekom, 2000; Filipovich, 2001; Seebörger, 2003). Since the revitalization of the irrigation scheme, new immigrants keep coming, and the population in the area has grown from barely 5,000 families in the early 1970s to about 35,000 now (Office du Niger, 2006; Seebörger, 2003). Even though ethnic homogeneity was established in every village when settlers moved in, the high turnover of plot holding in the early years, reallocation of plots after rehabilitation and continuous inflow of new farmers have mixed people with no common background within almost every village and even tertiary canal. Next, the economic growth triggered by the reforms went hand in hand with an economic differentiation between farmers. This differentiation has produced a considerable variability as to plot size, agricultural equipment, access to credit and availability of family labor (Jamin, 1994). To this adds a growing number of farmers that are outsiders to the village (so-called non-resident farmers). A few live in another village nearby, but most of them live in one of the small towns within the area of the irrigation scheme. Some even reside outside the irrigation scheme and have their land cultivated by wage laborers. For many non-residents, rice farming is often only a secondary activity. In the rehabilitated parts of the irrigation scheme, they comprise some 10 to 40 % of the farmers (Jamin and Doucet, 1992). In addition, even though illegal, leasing out plots for just one growing season has become quite common. Coulibaly and Bélières (2004) report that about 20 % of farmers lease out (a part of) their plot, and in total, leaseholders cultivate 7 % of the irrigated surface. Most leaseholders are also non-residents.

There exists a considerable antagonism between farmers and the central management. The Office du Niger was created by the French colonial power to supply France with cotton. The dam and irrigation infrastructure were built by forced laborers, and in a first phase, farmers were settled by force or with false promises. Extreme hard work and tough living conditions made many early settlers flee the irrigation scheme and mortality because of disease and exhaustion was extremely high. Only from the 1960s, farmers started to migrate voluntarily from their native land to the Office du Niger, often because of the drought ravaging the Sahel. Furthermore, until the reforms, farmers depended completely on the central management while they had very limited bargaining power (Davidse *et al.*, 1984). Nearly all decisions on production and marketing of the crop were taken at the level of the central management, reducing farmers to mere laborers (van Beusekom, 2000; 2002). At the end of the growing season, farmers were obliged to sell their crop to the central management at a pre-set price, with the "Economic Police" exerting tight control. The lucrative business of rice processing was again the monopoly of the central management. Next, many farmers ran up debts toward the central management, who had again a monopoly on credit (de Wilde, 1968; Kroon, 1979). The land question is a last delicate point. In the irrigation scheme, farmers cannot own any land, because it belongs to the Malian state. Most farmers only hold an annual land title that provides exclusive usufruct rights[1]. This land title is automatically renewed and in practice can be passed to heirs, as long as the water fee is duly paid (Jamin and Doucet, 1994). Since the early 1990s, farmers can obtain a "Permis d'Exploitation Agricole", which is an indeterminate contract passable to heirs but only a handful of farmers have obtained until now (see Box 8). Given their powerful position, the central management possessed a considerable authority over farmers (Kroon, 1979). This authority erodes progressively since the reforms, but still affects the relation between the management's agents and farmers.

[1] Because of the strict division of labor common in the area, rice cultivation is a male business, and almost all plot holders are men. The very few women who hold a land title by and large belong to the group of non-resident farmers and have another job. As a rule, they relay on wage laborers to actually cultivate the plot.

2.3 Stakeholder analysis of water management

The stakeholder analysis aims to identify the different stakeholders, their objectives and mental models concerning water management. It follows the theoretical framework developed by van Noordwijk *et al.* (2002) outlined in Figure 1.1. The analysis is limited to the tertiary level, which is the focus of this study. Particular attention goes to collective action, which farmers were assumed to establish after IMT. The stakeholder analysis is the result of semi-structured interviews with selected key-informants that took place in 2003 (see Appendix 3). As such, 22 functionaries from all levels of the hierarchy of the central management were interviewed, 43 farmers and 10 leaders from civil society in the study area, representing a farmers' syndicate, a federation of farmer organizations, research centers and local NGOs. Results were validated and adjusted in 2004 through a study on farmers' perceptions of water management (Bastiaens, 2005). In this study, discussion groups with different stakeholders were held. By running a participatory diagnostic of water management in 2006 (Colin and Petit, 2007), a second validation was achieved. Three stakeholder groups are considered:

- *Farmers*, who have to take the actual management decisions either individually or collectively with the group of farmers sharing a tertiary block;
- *The central management* of the Office du Niger, which tries to influence farmers' management decisions through training and sensitization and promotes the regulations stipulated by the negotiated contract. In the scope of this dissertation, the central management will in addition represent the Malian state, whose objectives it pursues following the negotiated contract (Office du Niger, 2005);
- *International donors*, who exert considerable influence on both the central management and farmers indirectly by setting the policy agenda, and directly through projects on water management. International donors' opinion counts heavily, as they finance most of the new irrigation infrastructure[1].

All groups are diverse. In particular, the central management contains officials with desk jobs at the headquarters or the directorates, but also field staff in direct contact with farmers. The analysis therefore only reflects general tendencies.

What unites all stakeholders is the production of irrigated rice, which they want to maximize under given constraints. Rice production is however instrumental to several other

[1] To give just a few examples, the USA will spend 234.6 million dollars over the next five years to develop 16,000 ha of newly irrigated land through its Millennium Challenge Corporation. The French 'Agence française de Développement' has approved a budget of 10 million euros on its coming PADON project, which aims to improve water management and will also develop newly irrigated land.

objectives. For farmers, it is a question of securing a livelihood for their families. As alternative economic opportunities present themselves, it might become a more or less important part in the portfolio of various sources of income. In contrast, the central management has a regional or even national perspective. Its objectives are on the one hand to combat rural poverty by raising farmer incomes and on the other hand to establish national food security and to export surplus production to neighboring countries (Office du Niger, 2005). International donors support these objectives, but their concerns extend beyond the Malian national interests. In particular, they take into account the actual and potential water users in up- and downstream countries of the Niger River.

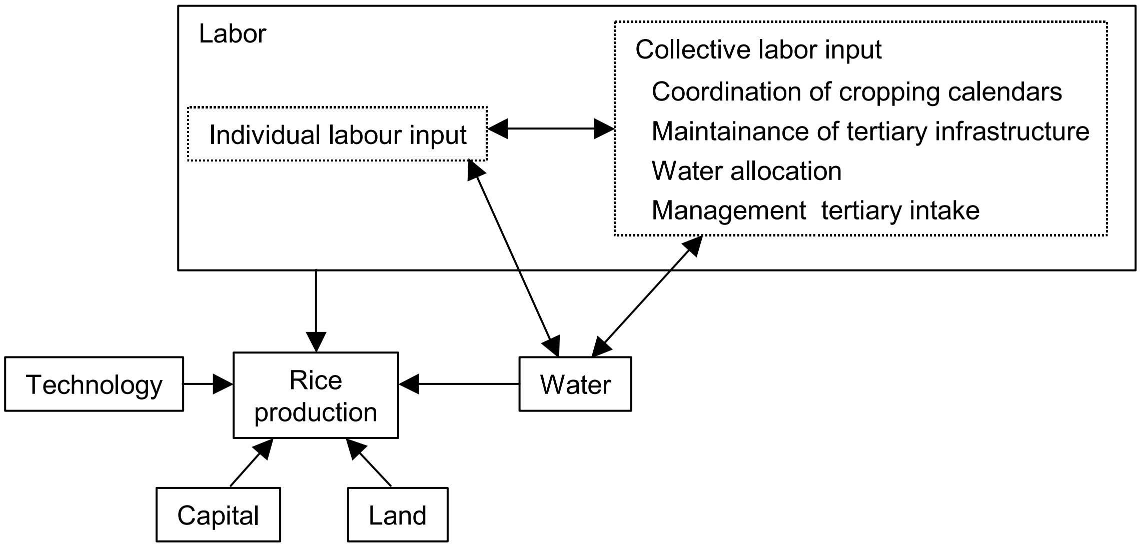


Figure 2.5 Production factors mobilized for rice cultivation

For rice production, several production factors are mobilized (Figure 2.5). Regarding these production factors, the different stakeholders appear to have diverging interests and priorities, translating in different strategies. In irrigated agriculture, water is a primary production factor. Up until today, during the main growing season, water is abundant in the Niger River and the irrigation network does not present structural bottlenecks. Irrigated land on the other hand is limiting, and stakeholders therefore want to maximize rice production per hectare. Farmers also consider labor as an important production factor. They value it highly since it comes at the cost of time available for other economic activities or leisure. With respect to water management, labor has a collective and an individual component. Collective water management tasks include adjusting water supply to the tertiary block to aggregate demand, allocating water among individual farmers, maintaining tertiary infrastructure and coordinating the cropping calendar. These tasks demand collective action by devising and monitoring rules and organizing joint activities. Individual water management tasks consists in supervising irrigation, maintaining contour dikes of rice basins and land leveling among others. In times of water temporary supply problems or for farmers with a disadvantageous plot location, monitoring and negotiating access to water increase individual labor input (Figure 2.5). Collective action might alleviate this extra labor input by regulating water allocation but requires sufficient social capital.

Technological innovation through the introduction of improved rice varieties and transplanting techniques made an important production increase possible (Jamin and Coulibaly, 2002). Capital (to buy fertilizer, sowing seed, equipment, etc.) is also crucial for production and at present a limiting production factor for many farmers (see Box 5). Given the huge untapped irrigation potential, the central management's main strategy to increase total rice output is however an expansion of the irrigated area (see Map 2.3), for which improving irrigation efficiency at the tertiary level is indispensable. The central management considers strengthening collective labor input as the key factor to increasing efficiency. Reasoning from its own mental model, it wants to promote a fully-fledged collective action for water management. In a first step, they concentrate on infrastructure maintenance. The presence of up to 2 m high weeds in the tertiary canals is perceived as an obstruction of the water flow inducing losses. It comes across as a strong and very visible indicator of current poor levels of collective action. International donors, who are concerned about water and infrastructure conservation as a matter of principle, very strongly support this position.

So far, the expansion plans have not yet been communicated to farmers, who consequently are not aware of the coming pressure on water. Furthermore, even though the expansion of the irrigated area will benefit future farmers who will gain access to an irrigated rice plot, those already in place will in principle not get extra land, and hence have no stake in the expansion. Consequently, they are not concerned about irrigation efficiency. On the contrary, the presently unrestricted and demand-driven water delivery under the current minimal water management strategies results in over-irrigation and thus low efficiency, but it makes irrigation easy. Under the current conditions, farmers can irrigate when they want and with the quantity desired. In their eyes, the level infrastructure maintenance is sufficient as long as it does not hinder this easy irrigation. What might motivate farmers to increase irrigation efficiency is the fact that over-irrigation might provoke drainage problems. But given the 'communicating vessels' aspect of the drainage system, the positive impact of a farmer's efforts dissipates throughout the irrigation scheme, and as such does not provide the necessary incentives to individual farmers or even farmer groups at tertiary level.

The central management would like to increase its grip on water management at the tertiary level, so that it can actively pursue its strategies and objectives. Here, they meet opposition from both international donors and farmers. International donors strongly believe that, if they possess the necessary social capital, farmers will be better at water management than the central management is. Consequently, they constantly push for farmer autonomy and count on the set up of Water Users Associations and extension and training campaigns to increase social capital. Farmers on the other hand fiercely defend the demand-driven water supply and even rise against any short-term supply disruption, as they consider easy irrigation an acquired right. They furthermore want to preserve their independence at the tertiary level, as it allows them to devote their labor as they think best.

The discrepancy in strategies and objectives of water management lies at the heart of the current conflict between farmers, the central management and international donors. Within their margins available, each stakeholder tries to impose their strategies on the others (Figure 2.6), and accuses themof the perceived failures. For the reasons mentioned in section 2.1 (Problem setting of the case study), this research supports the idea that irrigation efficiency at the tertiary level should be increased. At the same time, it wants to take into account the different stakeholders' interest. Therefore, the trade-off between water, collective action and individual water management practices is the focal point of this research. Relations among these variables are investigated in depth and it is explored how the social and institutional context influences the trade-off. The results of the analysis then serve as a basis during the design of the tools and guidelines to support farmers' water management.

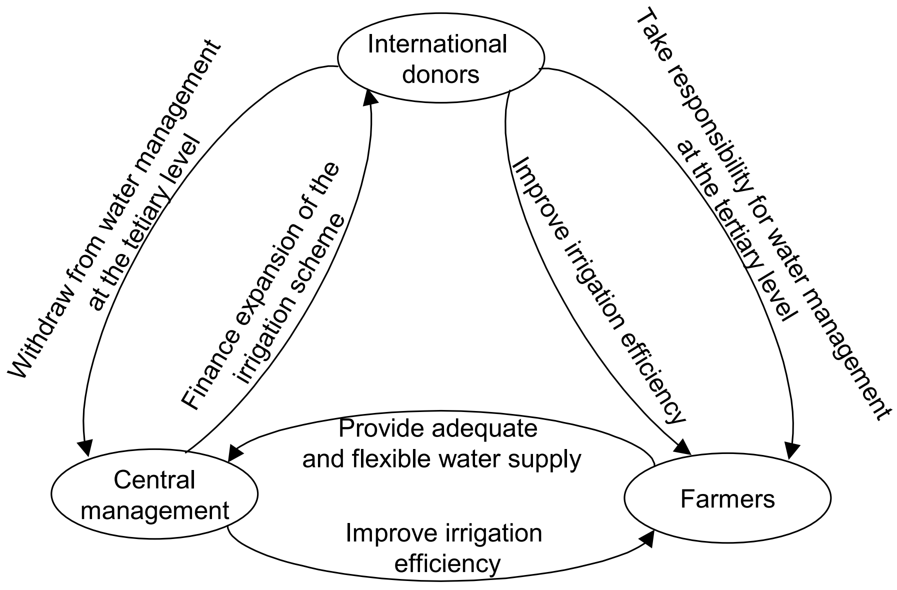


Figure 2.6 Outline of relations among the various stakeholders

PART I

ANALYSIS OF ORGANIZATION AND PERFORMANCE OF WATER MANAGEMENT

Summary

From the stakeholder analysis, it appeared that while the central management wants to increase irrigation efficiency through fully-fledged collective action, farmers value the latter only when it favors easy irrigation. Part I of this dissertation analyzes the impact of management on performance in the real world. A field study is conducted which investigates current farmers' water management practices after IMT, performance levels and possible connections between both. Results indicate that with water availability being abundant, farmers can avoid the need for cooperation by maintaining a constant over-supply of water. As a result, irrigation problems are rare, even though they exist in tertiary blocks with an uneven topography. In those cases, allocation rules can effectively solve irrigation problems. Lacking the necessary social capital, some farmer groups however do not succeed in establishing them. Minimal water management strategies result in low irrigation efficiency at the tertiary level, which is estimated at about 60 %. It has been shown that collective action at the intake of the tertiary blocks can improve irrigation efficiency with 14 %, which will be necessary as the irrigation scheme expands further and water becomes scarce. Furthermore, the over-supply of water is one of the major causes of the recurring drainage problems in the irrigation scheme, which incur an increase in production costs and a decrease of both quantity and quality of harvested rice. Maintenance of tertiary irrigation and drainage canals, as well as the dispersal of planting dates, is currently the focal point of interventions by the central management. Results however indicate that they do not influence performance significantly, which shows that a thorough analysis remains necessary for setting the problem statement right. The analysis leads to certain recommendations to guarantee the sustainability of the irrigation scheme's expansion. They concern targeting the interventions and propose a mix of incentives to improve water use, accompanied by measures of sensitization and capacity building.

Chapter 3

Irrigation performance at the tertiary level: Adequate water delivery through over-supply

Abstract[1]

The hydraulic performance of irrigation in the Office du Niger in 1995 is compared with the situation nearly ten years later (2004). Major physical rehabilitations and economic and institutional reforms carried out from the 1980s onwards succeeded in making a success story of the Office du Niger. This chapter analyzes the irrigation performance at the tertiary level in the light of the interventions implemented and current water management practices using the performance indicators proposed by Molden and Gates. The interventions succeeded in establishing a good adequacy of water supply (0,95 for 1995 and 0,91 for 2004), thus creating the necessary conditions for boosting rice production. Because of the minimal management strategies of farmers and water guards, efficiency is however low and shows no sign of improving between 1995 (0,52) and today (0,59). Dependability and equity are also poor according to Molden and Gates' criteria, but given that water supply is generally adequate, these indicators appear less relevant. An alternative calculation procedure is proposed for situations where water is not scarce. Results of the adapted indicators show satisfactory levels of dependability and equity. Measures aimed at increasing efficiency will inevitably be costly, but are redeemed justified. Indeed, even though water is not a limiting factor during the main growing season until today, this is to change soon as the irrigated surface will be strongly expanded. In addition, increased irrigation efficiency might help to solve the recurrent drainage problems that trouble the harvest in the Office du Niger.

[1] This chapter is adapted from: Vandersypen, K., Bengaly, K., Keita, A. C. T., Sidibé, S., Raes, D., and Jamin, J.-Y. (2006). Irrigation performance at the tertiary level in the rice schemes of the Office du Niger (Mali): Adequate water delivery through over-supply. Agricultural Water Management, 83, 144-152.

3.1 Introduction

In the frame of the reforms of the Office du Niger, rehabilitation of irrigation infrastructure was accompanied by a thorough reorganization of water management procedures. Hydraulic performance of irrigation, which was judged extremely low, was then expected to improve on all accounts. Before the interventions, water distribution was supply-driven. Water was conveyed to the canals following an irrigation schedule established by the central management. Water guards employed by the central management informed farmers when their block would be served and farmers were then required to irrigate their plots with the water available. Because of inadequate information about water requirements of different areas and incompetence in establishing the irrigation schedule by the central management, this system did not work well and created water shortages for whole areas. In addition, control over the water supply was virtually impossible: all canal intakes were non-modular and measurement structures for calculating flow rates did not exist. Besides, the specific water demand of the area to be served was unknown since information on the cultivated surface was unavailable. The management's strategy was therefore to supply a maximum of water to the scheduled canals and to evacuate the excess through the drainage system (Bastiaansen *et al.*, 1984). Even so, irrigation problems persisted on a large proportion of the irrigated area. First, the irrigation network was extensively degraded and large conveyance losses diminished the amount of water delivered to the field. Second, the land surface was badly leveled and higher parts had inadequate access to water. This effect was further intensified by the inexistence of a rotation system between field canals within the tertiary block, so that a high number of farmers usually irrigated simultaneously and the water level in the tertiary canals remained low (Bastiaansen *et al.*, 1984).

Water management was thus a major impediment to agricultural production while being extremely wasteful. The interventions of the international donors therefore intended to both improve the conditions for rice production and rationalize water use. They comprised three elements. First, a rehabilitation of the irrigation infrastructure was to establish full water control through land leveling, restoration of the irrigation network and installation of more sophisticated intake structures. Accompanying guidelines and procedures for operation of the infrastructure were supplied along with the rehabilitation. Second, in order to better match supply with demand, water distribution was shifted from a supply driven system to a demand driven system in which all secondary canals are permanently filled. Depending on whether the intake of the tertiary canal is locked, farmers can now either open the intake of the tertiary canal themselves, or communicate their water demand to a water guard who will open the intake of the tertiary canal accordingly. Then, at every level of the canal system, the total demand of the downstream canals is satisfied. To further improve the demand-driven system, each tertiary canal is supposed to be represented by a canal chief, whose task is to collect and communicate the future water demand of his fellow farmers to the water guard (van Keulen and Hamel, 1997). Finally, as part of IMT, water management within the tertiary block is entirely left to farmers (Touré *et al.*, 1997). As such, they can now decide independently on water allocation.

The transition to success of the Office du Niger would not have been possible without genuine improvements in water management. Several studies conducted in the 1990s demonstrate on the other hand that hydraulic efficiency at the tertiary level remains unsatisfactory (Konaté, 1991; Bengaly, 1995; Hamel *et al.*, 1996, Ouvry and Marlet, 1999). Those studies however provide an incomplete picture since they do not take into account adequacy, dependability and equity of water delivery that might explain the success of the interventions on other domains. Therefore, this chapter assesses hydraulic performance during the main rice-growing season and at the tertiary level in the Office du Niger by using the performance indicators proposed by Molden and Gates (1990), which include all four aspects mentioned above. The performance of 1995, just after the reforms, is compared with the situation in 2004, 9 years later. Results are then analyzed in the light of the interventions implemented in the irrigation project and current water management practices. Finally, some recommendations are formulated.

3.2 Materials and methods

Characteristics of the samples of tertiary canals

Data from 1995 and 2004 are collected on samples of tertiary blocks selected independently from each other. The 2004 sample contains 36 tertiary blocks and is composed in the frame of this dissertation to evaluate farmers' organization and performance of water management. From that sample, 24 blocks from two administrative zones (Niono and N'Debougou) with a sufficiently complete data set are selected. The blocks belong to six secondary canals, divided into several independent hydraulic units through control structures. The sample contains 13 of those units with no more than three blocks in each. Furthermore, within this sample, both the Retail and Arpon type of infrastructure figure (see Table 2.1 for a description of the characteristics of both types). The 1995 sample was constructed in the scope of a study on irrigation efficiency by Bengaly (1995). It contains 20 tertiary blocks, all of which are of the Retail type and situated in the Niono zone. The sample contains 14 independent hydraulic units from 5 secondary canals, with once again no more than three blocks per unit. None of them overlaps with the blocks from the 2004 sample. Table 3.1 summarizes the characteristics of both samples. Differences in irrigated surface and number of farmers on the canal are not necessarily representative for the type of infrastructure.

Table 3.1 Summary characteristics of the samples of tertiary blocks

Particulars	1995	2004		
		Retail	Arpon	Total
Number of tertiary blocks in the sample	20	12	12	24
Number of independent hydraulic units in the sample	14	6	7	13
Number of secondary canals in the sample	5	3	3	6
Average surface of the tertiary blocks (ha)	26 (13)	15 (10)	25 (12)	20 (11)
Average length of the tertiary canals (m)	1024 (489)	707 (281)	977 (288)	842 (276)
Average number of farmers in the tertiary blocks	18 (15.1)	8 (3.2)	9 (4.8)	9 (3.8)
Average design flow rate of the tertiary canals (l/s/ha)	2.40 (0.49)	2.59 (0.99)	1.99 (0.23)	2.29 (0.89)

Source: land register of the Office du Niger
Figures between parenthesis show standard deviation

Performance indicators

The performance indicators proposed by Molden and Gates (1990) are adequacy (P_A), efficiency (P_F), dependability (P_D), and equity (P_E):

$$P_A = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_A\right) \quad \text{with} \quad p_A = \frac{Q_D}{Q_R} \quad \text{if} \quad Q_D \le Q_R \quad \text{and} \quad p_A = 1 \quad \text{otherwise} \tag{1}$$

$$P_F = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_F\right) \quad \text{with} \quad p_F = \frac{Q_R}{Q_D} \quad \text{if} \quad Q_R \le Q_D \quad \text{and} \quad p_F = 1 \quad \text{otherwise} \tag{2}$$

$$P_D = \frac{1}{R}\sum_R CV_T\left(\frac{Q_D}{Q_R}\right) \tag{3}$$

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_D}{Q_R}\right) \tag{4}$$

The indicators compare the volume of water required (Q_R) with the water delivered (Q_D) of a certain subregion (R) during a certain period (T). CV is the coefficient of variation. *Adequacy* assesses whether the amount of water delivered meets the requirement. When delivery exceeds requirements in a certain period, it is considered fully adequate. *Efficiency* is a measure for the excess of water delivered in comparison with the requirements. A delivery of less than the required amount is thus considered fully efficient. *Dependability* expresses the degree of temporal variability of irrigation delivery compared to requirements. It thus assesses whether adequate water quantities arrive at the required time and place. *Equity* is a measure for the spatial uniformity of water deliveries and shows the fairness of water delivery across delivery points. Since dependability and equity are expressed by a coefficient of variation (CV), the lower the value, the higher the dependability and equity. In addition, an alternative calculation procedure for dependability and equity of water delivery is proposed that might better suit situations where water is not scarce, as is the case in the Office du Niger. This procedure introduces a maximum threshold of one for the ratio of Q_D over Q_R when water delivery is fully adequate (as for the calculation of adequacy) so that variation in over-supply is eliminated in the indicator:

$$P_D' = \frac{1}{R}\sum_R CV_T(p_A) \quad \text{with} \quad p_A = \frac{Q_D}{Q_R} \quad \text{if} \quad Q_D \le Q_R \quad \text{and} \quad p_A = 1 \quad \text{otherwise} \tag{5}$$

$$P_E' = \frac{1}{T}\sum_T CV_R(p_A) \quad \text{with} \quad p_A = \frac{Q_D}{Q_R} \quad \text{if} \quad Q_D \le Q_R \quad \text{and} \quad p_A = 1 \quad \text{otherwise} \tag{6}$$

Spatial averages are weighted against the surface of the tertiary blocks in order to take into account their relative importance. For this study, the subregion (R) consists of the total area covered by the sampled tertiary blocks. Tertiary blocks belonging to the same hydraulic unit are however not independent and are consequently replaced by their weighted average, so that the 1995 sample has 14 observations and 2004 sample 13. The period (T) covers 5 months of the rainy season (June to October), which corresponds to the main growing season. Since water can be stored in the rice basins, excess delivery at one moment compensates for shortage of delivery on a previous moment. Therefore, water requirement and delivery are calculated over intervals of one month. Differences between samples and types of infrastructure were tested with one-way ANOVA tests. Since equity is calculated as the coefficient of variation over tertiary blocks, samples cannot be compared statistically.

Water requirement (Q_R)

The water requirement of paddy rice is composed of evapotranspiration from the rice basins (ET_{rice}), water used for land preparation (PREP) and the water added to establish a water layer in the field (LAYER) to improve paddy growth and improve production conditions

(Anbumozhi *et al.*, 1998). The evacuation of this water layer for harvesting allows furthermore for alkalinity control (N'Diaye and Guindo, 1998; van Asten *et al.*, 2004).

The evapotranspiration is obtained by multiplying the reference evapotranspiration (ET_0) with a crop factor (k_c). Reference evapotranspiration is calculated using the Penman equation (Doorenbos and Pruitt, 1977), which corresponds best to measured evapotranspiration levels in the Sahel region (Raes *et al.*, 1995). A crop factor of 1.2 for paddy rice is applied (Hendrickx *et al.*, 1986). Land preparation, which includes plowing and/or harrowing, requires 1500 m³/ha for land soaking and establishing a small water layer under good management conditions and on level fields (Hendrickx *et al.*, 1986). Farmers carry it out once at the onset of the growing season (Jamin, 1994) at about 25 to 30 days before transplanting. The day before transplanting, they add a water layer of 50 mm, which they increase to 100 mm after 25 days and to 150 mm after 70 days. Rainfall that is effectively stored in the rice basins (P_{eff}) meets a part of the crop's water need and can be fully subtracted from the irrigation requirement. In the region, all rainfall on a transplanted surface is considered effective (Hendrickx *et al.*, 1981). Finally, Molden and Gates allow for conveyance and percolation losses downstream of the considered delivery point. In the design of the irrigation infrastructure, losses of about 25 % of the irrigation requirement were taken into account at the level of the tertiary block (Bastiaansen *et al.*, 1984; Sogreah, 1982; AHT International, 1997). Losses caused by seepage in canals and deep percolation are almost negligible in the region because of the low permeability of the soil and the fact that the water table almost reaches the soil surface during the rainy season (Hendrickx *et al.*, 1986). The 25 % increase can thus be considered as conservative. The water requirement per hectare for a certain period at the intake of the tertiary canal is computed as:

$$(ET_{rice} + PREP + LAYER - P_{eff}) \cdot 1.25 \qquad [m^3/ha]$$

Daily meteorological data are obtained from the Direction National de la Météorologie regional offices in Niono and Ségou. Finally, the transplanted and harvested surfaces as well as the surface of nurseries were monitored for each of the tertiary blocks throughout the growing season.

Water delivery (Q_D)

Flow rates at the intake of the tertiary canals are not routinely recorded. In the scope of the 1995 and 2004 studies, the instant flow rates at the intake of the canals from the samples were measured daily during the growing season and considered constant for that day. This is justified because with irrigation continuing 24 hours out of 24, the opening of intakes usually remains unchanged throughout the day (Office du Niger, 1990). Furthermore, fluctuations in water levels of the secondary canal have little impact on the intake flow rate in Retail type intakes, which use baffle modules. Errors could be more important in the case of the semi-modular sliding gates of the Arpon type intakes and are estimated at five to ten percent of delivered daily volumes. Nevertheless, fluctuation of the upstream water level being non-systematic, errors are assumed to level each other out. Flow rates were recorded from the beginning of June until the end of October, covering the bulk of the main rice-growing season.

3.3 Results and discussion

3.3.1 Irrigation performance

Adequacy and Efficiency

Results show that the total water requirement from June to October varies little among the tertiary blocks and between the years and are around 9000 m^3/ha (Table 3.2). The variations in ET_{rice} + PREP + LAYER and effective rainfall are due to differences in the evolution of the planted surface of the tertiary blocks. When comparing (Figure 3.1) the irrigation requirement (Q_R) with the volumes delivered (Q_D), it is obvious that deliveries exceed requirements on a seasonal basis in every block, except for two (one in each sample). At a monthly basis as well, requirements of the sampled tertiary blocks are generally covered by deliveries, translating into an adequacy indicator of 0.95 for the 1995 sample and 0.91 for the 2004 sample (Table 3.3 and Figure 3.2), which is judged 'good' by the standards put forward by Molden and Gates (1990). In general, water management in the Office du Niger thus succeeds in establishing good conditions for rice production. In contrast, the efficiency reaches only 0.52 and 0.59 for the 1995 and 2004 samples respectively, judged 'poor' by Molden and Gates (1990). Losses are due to excess water delivery in the tertiary canals compared to demand and excess application to the fields. As a result, irrigation water flows directly to the drainage system through (i) the overflows in the tertiary canal, (ii) the outlet towards the drainage system of the field canals and (iii) breaches in the dikes contouring the rice basins. Consequently, the excellent adequacy is achieved by massive over-supply.

In the light of the interventions described, a striking result of the 1995 and 2004 data is that they were successful in providing adequacy of water delivery while having insufficient impact on efficiency. In reality, the chief accomplishments were the restoration of the irrigation network and land leveling. Most of the water delivered to the canals at the head of the system now reaches the tertiary blocks and thanks to land leveling, areas difficult to irrigate have become rare. Moreover, the failures of the irrigation schedule are eliminated, since all secondary canals are now permanently filled. In contrast, the interventions hardly make a difference as to water management. First, water control is still incomplete. Guidelines and procedures for operation, such as the surface controlled per water guard and presence of the latter in the field are not followed in practice. Water guards furthermore lack the proper training for their job. As a result, operation of the irrigation network is inadequate. Moreover, with measurements of flow rates in primary and secondary canals being irregular, and with no measurements at the intakes of tertiary canals, knowledge on supplied volumes is still incomplete.

Table 3.2 Average water requirement and delivery (m^3/ha) from June to October

Water requirement and delivery	1995	2004		
		Retail	Arpon	Total
ET_{rice} (1) + PREP (2) + LAYER (3)	9730	10 257	10 074	10 138
P_{eff} (4)	2914	2723	2937	2862
Q_R (5)	8520	9417	8922	9096
Q_D (6)	17 601	21 983	14 253	16 966

(1) Evapotranspiration from the rice basins
(2) Water used for land preparation
(3) Water added to establish a water layer in the field
(4) Rainfall that is effectively stored in the rice basins
(5) Volume of water required
(6) Volume of water delivered

Table 3.3 Summary of performance indicators

Performance indicator	1995	2004			Results from one-way ANOVA tests for differences between	
		Retail	Arpon	Total	Years	Types
Adequacy (Eq. 1)	0.95	0.95	0.89	0.91	$F_{1,18} = 0.000$ $p = 0.996$	$F_{1,11} = 2.094$ $p = 0.176$
Efficiency (Eq. 2)	0.52	0.47	0.65	0.59	$F_{1,18} = 0.251$ $p = 0.622$	$F_{1,11} = 6.949$ $p = 0.023$
Dependability (Eq. 3)	0.78	0.67	0.72	0.71		
Dependability[1] (Eq. 5)	0.08	0.12	0.21	0.18	$F_{1,18} = 0.332$ $p = 0.571$	$F_{1,11} = 1.414$ $p = 0.259$
Equity (Eq. 4)	0.63	0.47	0.59	0.54		
Equity[1] (Eq. 6)	0.11	0.10	0.16	0.14		

[1] using an alternative calculation procedure introducing a maximum threshold of one for the ratio of Q_D over Q_R when water delivery is fully adequate

Second, the demand driven system gives rise to the same supply strategies as before. Procedures on communication about future water demands between farmers and their canal chief, and then between canal chiefs and water guards are not followed. Conseuqently, water guards keep canals constantly at maximum capacity in order to be able to fulfill on the spot demands. To this adds the fact that tertiary canals are often over-dimensioned, both for practical construction reasons and in order to allow for flexibility in the water supply. Whereas the peak requirement of the paddy fields is calculated at 1.5 l/s/ha (Bastiaansen *et al.*, 1984), design flow rates of tertiary canals are rather around 2 to 2.5 l/s/ha. This ample water availability might ensure a good adequacy of water supply, but also gives rise to losses in the tertiary canals. Indeed, excess supply over demand and favors excess application since farmers have no economic incentives to use water more efficiently. The water fees they pay are based on the cultivated surface and independent of volumes consumed. Third, with farmers being responsible for water management within the tertiary block, water distribution functions mostly in absence of coordination (Chapter 4). This system can be sustained thanks to the abundant supply, once again leading to conveyance losses and excess application.

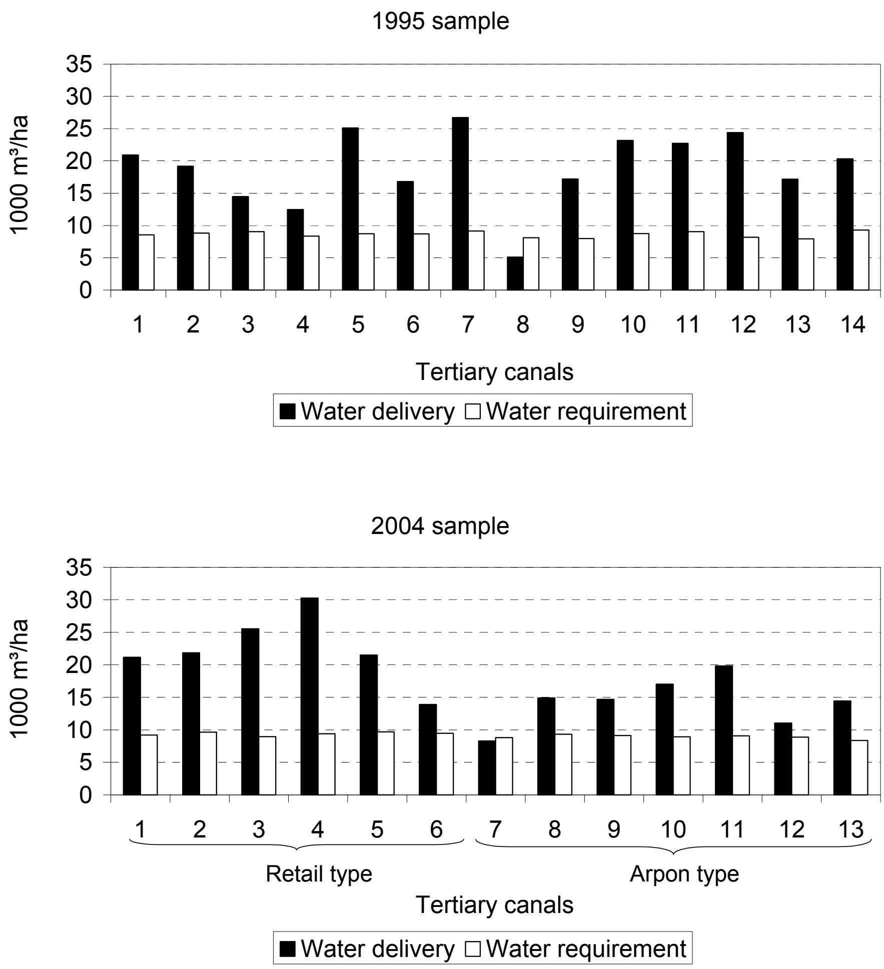


Figure 3.1 Total water requirement and delivery for the sampled tertiary blocks from June to October in 1995 and 2004

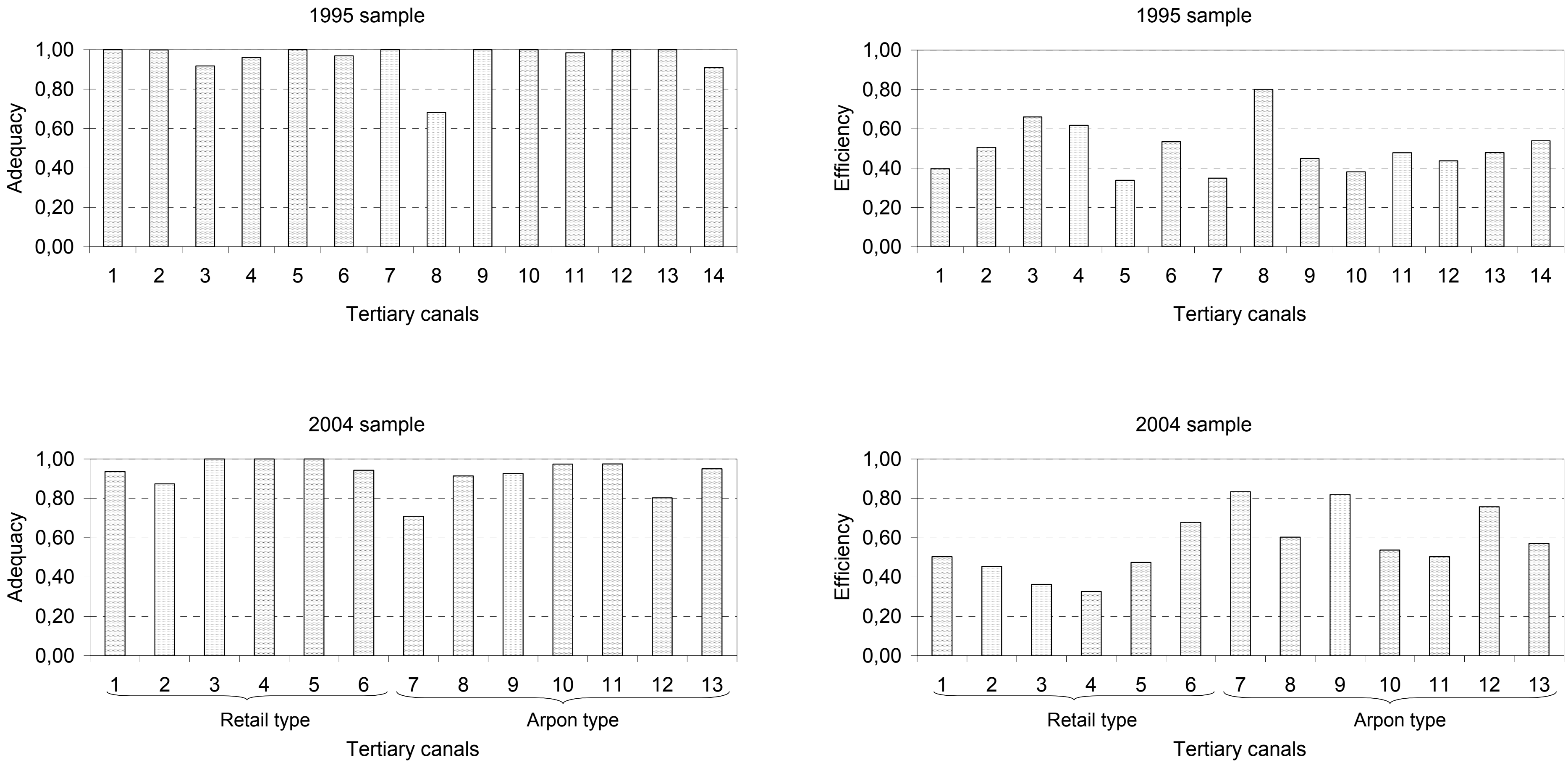


Figure 3.2 Adequacy and efficiency of water delivery in 1995 and 2004

Dependability and equity

The total water delivery with respect to requirement varies considerably among tertiary blocks (Figure 3.1) and within the blocks over the months. This results in indicators of 0.78 and 0.71 for dependability and 0.63 and 0.54 for equity for the 1995 and 2004 samples respectively. Such results are far beyond the thresholds accounting for 'poor' (0.25 for dependability and 0.2 for equity). Nevertheless, since adequacy is excellent for almost all tertiary blocks throughout the growing season (Figure 3.2), the indicators do not imply that water supply is unreliable or unfair but rather present a measure of the temporal and spatial variability in over-supply. As such, the results suggest that characteristics and events proper to the tertiary blocks might explain the over-supply. Further research might shed light on the causes of these differences and help to improve performance.

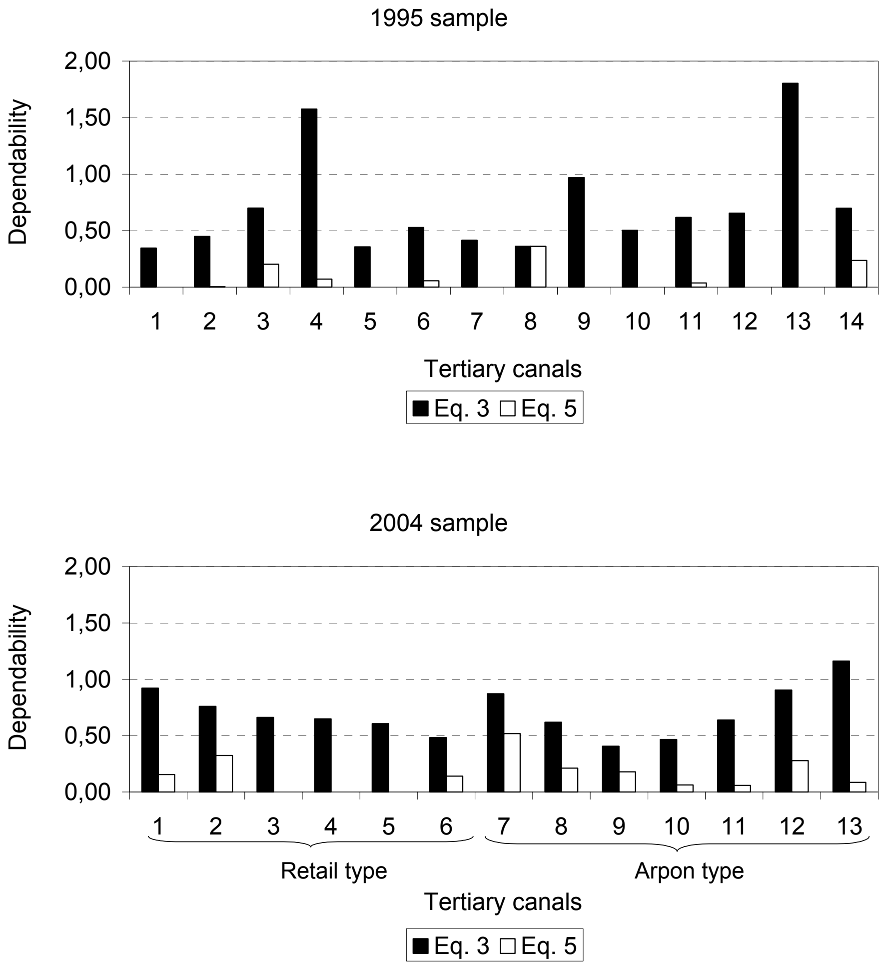


Figure 3.3 Dependability of water delivery (Eq. 3 versus Eq. 5) in 1995 and 2004

When using the alternative calculation procedure, dependability is however 0.08 for the 1995 sample and 0.18 for the 2004 sample. Equity then amounts to 0.11 and 0.14 respectively

(Table 3.3 and Figure 3.3). Performance is thus judged 'fair' (indicators between 0.11 and 0.20) or even 'good' (indicators lower than 0.10) according to Molden and Gates' criteria (1990), which corresponds better to the reality of the study area. These results confirm that currently, water management is satisfactory for most of the tertiary blocks and most of the time. The adapted indicators will be used for further analysis in the remainder of this chapter.

3.3.2 Evolution of performance between 1995 and 2004

The 1995 and 2004 growing season are compared for the Retail type of infrastructure only. Results show a status quo as to irrigation performance. Indeed, differences in adequacy, efficiency and dependability between the 1995 and 2004 sample are not significant (one-way ANOVA: $F_{1,25} = 1.142$, $p = 0.295$, $F_{1,25} = 1.722$, $p = 0.201$ and $F_{1,25} = 2.829$, $p = 0.105$ respectively), and values for equity are quite close (Table 3.3). Since the reforms were just completed in 1995, it is reasonable to assume that performance would improve as farmers and water guards come to understand better their new roles and responsibilities over the years. Instead, it seems that they have hardly changed their habits. With adequacy, dependability and equity of water delivery being satisfactory, and with no incentives to rationalize individual water consumption, they have no reason to take the trouble to improve efficiency as well. Many farmers nevertheless complain about drainage problems (Keita, 2003). Most areas in the irrigation project have no natural drainage outlet, and drainage water is conveyed to depressions in the desert (Hendrickx *et al.*, 1986). These depressions fill up with the excess of water delivered to the area, so that drainage of the rice basins at harvest becomes virtually impossible (Van der Walle, 1982). As a result, production costs increase and rice quality reduces. No direct link exists though between the efficiency of water delivery and drainage problems at the level of an individual plot or even a tertiary block. Since the drainage network has no regulating structures, the different drainage canals function as communicating vessels. Consequently, the lowest plots are the ones to suffer most from a saturated drainage system, regardless of their own efficiency or that of their tertiary block. In contrast, it can be expected that adequacy would deteriorate as the irrigation network degrades gradually. This has not yet happened, even though the rehabilitation was carried out 10 to 25 years ago on the majority of the tertiary blocks. Maintenance, even if often judged quite poor, has thus been satisfactory as to ensure a good adequacy of water delivery, mainly thanks to the over-dimensioning of tertiary canals.

3.3.3 Irrigation performance for different types of infrastructure

The 2004 sample shows no significant differences for adequacy and dependability of water delivery between the two types of infrastructure (one-way ANOVA: $F_{1,11} = 2.094$, $p = 0.176$ and $F_{1,11} = 1.414$, $p = 0.259$ respectively). The adequacy of the Arpon type tertiary blocks is 0.89 (‘fair’), which falls just below the threshold of 0.90 (accounted as ‘good’) proposed by Molden and Gates (1990), whereas the adequacy of the Retail type tertiary blocks reaches 0.95 (‘good’). Similarly (Table 3.3), dependability for the Arpon type is 0.21 (‘poor’), which lies just beyond the 0.11-0.20 range (accounted as ‘fair’), whereas the Retail value is 0.12 (‘fair’). Values for equity are quite close for the two types of infrastructure (0.16 for Arpon and 0.10 for Retail). On the other hand, efficiency is significantly higher for Arpon (0.65) than for Retail (0.47) (one-way ANOVA: $F_{1,11} = 6.949$, $p = 0.023$). Yet, the baffle modules (Retail type) offer greater control over the inflow than the semi-modular sliding gates used in the Arpon type and should allow a better efficiency. The minimal management strategy from both farmers and water guards however annihilates possible advantages of one over the other. Furthermore, the smaller design flow rate of most Arpon type tertiary blocks might reduce water losses and excess application. The results for adequacy and dependability suggest that the higher efficiency for the Arpon type is rather achieved through an inadequate supply to the tertiary blocks of this type in the sample during one or more months. With the intake being farmer-operated, the cause must either lie in a limited water availability at secondary level, or the use of water from drainage canals, as is observed in some lower lying tertiary blocks from the sample. In general terms, it can be stated that under current management conditions, the type of infrastructure has no impact on performance. Box 3 discusses the merits of the rehabilitation more generally.

3.3.4 Improving irrigation performance

In view of the expansion of the irrigation scheme, national and international competition for water and the recurring drainage problems, increasing irrigation efficiency will be necessary (Chapter 2). By comparing the irrigation efficiency at different levels in the irrigation project, Vandersypen *et al.* (2005) have shown that the tertiary level accounts for 26 % of total water losses. As in the calculation of water requirements, inevitable losses are already included, they correspond exclusively to management losses and could be reduced to zero. With the conveyance efficiency of the head works, primary and secondary canals remaining equal, an expansion of the irrigated surface with 20,000 hectares would be possible without an increase in total water consumption. This estimate can even be considered conservative, because the new irrigated areas will use the existing head works, whose losses are quite independent of volumes transported.

Box 3 Does rehabilitation make sense?

There has been a long-standing debate on the merits of the Dutch versus the French approach to rehabilitation (see Table 2.1). The Dutch used the cheaper Arpon-type of infrastructure, and emphasized farmer participation and learning. The French used the more expensive Retail-type and focused on intensification of rice production. To achieve this, fields were laser-leveled. Whereas the French approach resulted in a sudden jump in production, the difference in yield per hectare between the two approaches disappeared over the years (IOV, 1992). Indeed, farmers in areas rehabilitated by the Dutch gradually copied techniques introduced by the French and leveled their fields. Even the merits of rehabilitation as such can be questioned, since yields in not rehabilitated areas are also catching up. According to data of the central management, average yields in 2005 were 6.4 t/ha for rehabilitated areas and 5.8 t/ha for not-rehabilitated areas. As water control is incomplete in these areas, farmers have to irrigate more carefully. Nevertheless, they are not necessarily demanding rehabilitation. Anecdotic evidence suggests that the central management even uses rehabilitation as a threat to make farmers maintain tertiary infrastructure. While yields are nearly as high, the water fee in not-rehabilitated areas is only 85 % of the full price. Yet, the debate can even be carried further. On the edge of the irrigation scheme, farmers have constructed illegal outlets on irrigation and drainage canals to irrigate plots, the so-called “hors-casiers”. According to the same 2000 census, yields in those areas average 3.9 t/ha. This demonstrates that farmers are willing and able to upgrade or develop irrigation hardware when they are convinced of the benefits. This makes it a perfect argument to promote the participatory construction of infrastructure. Although this is the new approach in the Office du Niger, experiences so far are intriguingly rather disappointing (see Box 11).

For improving efficiency at the tertiary level while maintaining the good adequacy, dependability and equity of water delivery, investment in water management is required. First, more and better-trained water guards will be needed to establish full water control in the irrigation network. Second, farmers, tertiary canal chiefs and water guards ought to be incited to implement existing or improved procedures for matching water supply with demand, so that no water is delivered without being used by the farmers. Third, farmers must be motivated not to demand or use more water than required by their crops. The difficulty here is that at individual level, there will be no advantage of the increased effort of negotiating water supply and monitoring irrigation. Providing incentives based on actual water deliveries comes however at a cost. It requires measurement structures and regular monitoring by water guards. Moreover, measuring delivery to individual plots is virtually impossible with field intakes being shared among several farmers. Incentives that play at the collective level of a tertiary block put more pressure on farmer groups to distribute water equitable between their plots. Until now, farmers have shown little inclination towards organizing and coordinating water distribution, and the big risk is therefore that higher efficiency at the tertiary level will imply irrigation problems of certain plots within the tertiary block. Consequently, such incentives cannot go without serious investments in the functioning of these farmers groups. Unfortunately, recent efforts to organize farmers around maintenance of the tertiary infrastructure have bore meager results up until today.

So, any serious attempt in improving the efficiency at the tertiary level while maintaining the good levels for the other performance indicators is likely to increase the cost of rice production at the Office du Niger. The increased rice production as a result of the expansion of the cultivated area and the reduction of drainage problems at harvest might however justify the extra cost of improving efficiency at the tertiary level, while sustaining the good adequacy, dependability and equity.

3.4 Conclusions

International donors have invested in the Office du Niger from the 1980s onward with the purpose of making it profitable and boosting its rice production. Until then, the inadequacies of water management led to water shortages for certain areas as well as vast losses. The donors imposed a series of interventions that included a physical rehabilitation of the irrigation network and management reforms, making water supply demand-driven and establishing farmers' participation in management decisions. The evaluation of the impact of the interventions on water delivery performance revealed that adequacy of water delivery is good, but efficiency remains poor. The dependability and equity as calculated with the alternative procedure are satisfactory.

The physical rehabilitation of the irrigation network and the fact that water is made permanently available in the whole network made the irrigation delivery service excellent. On the other hand, the system is managed with minimal effort from both farmers and water guards. There is no evolution in performance between 1995, when interventions were just completed, and 2004, showing that incentives to improve water management are absent. Furthermore, the minimal management strategies cancel out possible advantages of different types of infrastructure as to irrigation performance.

A systematic over-supply is possible because water is no limiting factor during the main rice-growing season. Large conveyance losses and excess application within the tertiary block are a matter of course. As a result, the drainage system is almost perpetually saturated, making drainage of fields at harvest difficult. Drainage problems of an individual field however rather result from its location in the system than its level of water consumption, thus creating no incentive to use water more rationally. Consequently, it can be expected that despite persistent drainage problems caused by over-supply of water, improving irrigation efficiency remains difficult as long as water is abundant. Current levels of water consumption are however unsustainable given the rapid expansion of the irrigated area of the Office du Niger. Improving efficiency while maintaining good levels for adequacy, dependability and equity will require costly investments in water management. An effective water control demands more and better-trained water guards, who communicate regularly with farmers and canal chiefs in order to coordinate water delivery with demand. Most importantly however, farmers must be motivated not to demand more water than necessary. Providing incentives for water saving inevitably demands a tighter control of consumptions and should be accompanied by a reinforcement of farmers groups so that water within the tertiary block is distributed in a fair and efficient way.

Chapter 4

Sustainability of farmers' organization of water management

Abstract[1]

In the Office du Niger irrigation scheme, water allocation and maintenance at the tertiary canal level were left to farmers. In this chapter, their ability to resolve collective action problems through devising, monitoring and enforcing rules is diagnosed through a questionnaire survey with 89 farmers on 59 tertiary canals from five villages. Results show that rules are devised only on 30 % and 24 % of the canals for water allocation and maintenance respectively. Moreover, there is often no consensus on rules among farmers, and monitoring and sanctioning mechanisms are absent. This results in individualistic behavior causing problems concerning water allocation and maintenance for respectively 20 % and 43 % of the interviewed farmers. Ineffectiveness of peer pressure and farmers' incomplete mentality shift towards assuming collective responsibility are impediments to successful organization of water management. With water supply being abundant and the infrastructure recently rehabilitated, organization of water management at the tertiary level is however not always required in order to avoid problems. On the other hand, the current state of affairs is not considered sustainable, as the irrigated area will strongly expand and irrigation infrastructure ages with time. Measures of sensitization and group empowerment accompanying the process of management transfer will therefore be desirable.

[1] This chapter is adapted from: Vandersypen, K., Keïta, A. C. T., Kaloga, K., Coulibaly, Y., Raes, D., and Jamin, J.-Y. (2006). Sustainability of farmers' organization of water management in the Office du Niger irrigation scheme in Mali. Irrigation and Drainage, 55, 51-60.

4.1 Introduction

IMT makes farmers collectively responsible for water management in (part of) the irrigation scheme. In order to overcome the collective action problems typical of collective irrigation schemes, such as overuse of water and underinvestment in maintenance, they need to devise certain rules that promote the collective interest. However, farmers are not necessarily in a good position to assume these responsibilities, and the socio-cultural and historical setting do not always facilitate a smooth transition. First, it requires a radical mentality shift from farmers who until then were in a purely dependent position in relation to the central government (Shah *et al.*, 2002). Second, it demands social capital, which consists of trust, common rules, norms and sanctions and feelings of connectedness (Pretty, 2003). The historical legacy and socioeconomic and institutional setting of the Office du Niger present several constraints that might complicate successful farmers' water management. A first constraint is that until the reforms, they had no experience whatsoever with water management. Nearly all decisions on production and marketing of the crop were taken at the level of the central management, reducing farmers to mere laborers (van Beusekom, 2000). This has created a state of dependency, depressing entrepreneurial spirit and implying that all knowledge and institutions for water management have to be created from scratch (Shah *et al.*, 2002). A second constraint comprises the heterogeneity of the population of the Office du Niger as to socio-cultural background, endowments and interest. It is often assumed that differences in socio-cultural background reduce the social capital of a group, and as such reduce the potential for cooperation (Pretty and Ward, 2001). Keita (2003) points out that in the Office du Niger, differences in endowments and interests cause farmers' priorities and capacities to diverge and as such complicate cooperation. The third constraint concerns the absence of formal organizations of water management at the tertiary level, which might imply an extra barrier to cooperation (Ostrom, 1992; Meinzen-Dick *et al.*, 2002). WUAs are set up at the village level but are not fit to deal with the cooperation of farmers on the separate tertiary canals. Recent efforts to fill this void by creating tertiary level WUAs bore meager results up until today (Chapter 7).

The objective of this chapter is therefore to diagnose farmers' organization of water management at the tertiary level, focusing on two principal activities of water management: water allocation and maintenance. For both activities, the rules in use and their ability to resolve possible collective action problems are assessed. Subsequently, the impact of the type of infrastructure on the rules is examined. Next, the chapter looks at the possible impediments to successful farmers' organization of water management. Finally, some conclusions and perspectives are formulated.

4.2 Reform of water supply and canal maintenance

As explained in Chapter 3, since the reforms, all secondary irrigation canals are continuously filled and water supply is demand-driven. Taking turns in irrigation is only necessary between field canals of the same tertiary block. Indeed, the rehabilitated irrigation infrastructure is designed such that not all field canals on a tertiary canal can be served simultaneously with an adequate flow rate. In the irrigation manuals supplied along with the rehabilitation, engineers prescribe that water allocation should follow a fixed rotation scheme between individual field canals on a weekly basis. It is however left to farmers to implement this rule in practice or to organize water allocation in some other way.

As to maintenance, farmers used to pay every year a guarantee for the tertiary infrastructure, which would be reimbursed when they carried out the maintenance of their canal. Otherwise, the central management would use the money to pay a third party for carrying out the maintenance. In practice however, for decades neither did farmers the maintenance work themselves, or did the management employ others to do it instead. This resulted in advanced degradation of canals, as they filled up with aquatic weeds and debris and their banks crumbled. Upon restructuring, this system was abandoned and now, farmers are simply required to carry out maintenance themselves. Organization and monitoring of this task are also left to farmers. The unlined irrigation canals of the Office du Niger are vulnerable to weed growth and deterioration of the canal bed. Regular maintenance consists of removing aquatic plants from the canal and keeping the banks clear. It should be performed once or twice per growing season. Maintenance that is more thorough requires a dredging of the canals and is necessary every two or three years. This chapter focuses on the organization of regular maintenance.

4.3 Materials and methods

Sample

This study is a part of a broader research on strategies of water management at both the plot level and the level of the tertiary canal. The research took place in three of the administrative zones (Niono, N'Debougou and Molodo), which contains the research population. For reasons of convenience, a two-stage sampling method was used. First, five villages were selected and then in each village, about 20 farmers were picked out at random. For the purpose of this study, farmers being alone on a tertiary canal were left out of the sample, which now contains 89 farmers from 59 tertiary canals. The villages are quite similar as to total number of families, number of tertiary canals and average plot size of the farmers. Table 4.1 shows summary statistics about the villages. The sample villages were chosen such that four different methods of rehabilitation are represented, plus an area that has not yet been rehabilitated, and can be considered representative. The Retail-type as described in Table 2.1 contains three sub-types with each some specific characteristics shown in Table 4.2.

Table 4.1 Summary statistics of the study villages and sample[a]

Particulars	Name of village				
	Coloni	Foabougou	Banisiraela	Siengo	Siby
Type of infrastructure	Retail	Arpon	KfW	World Bank	Not-rehab.
Administrative zone	Niono	Niono	N'Debougou	N'Debougou	Molodo
Total number of secondary canals	1	2	1	1	3
Total number of tertiary canals	33	34	29	31	42
Total number of tertiary canals in the sample	12	15	11	12	9
Total number of farmers in the village	263	194	145	162	126
Total number of farmers in the sample	20	20	19	19	11
Average plot size in the village (ha)	2.1	3.1	3.4	2.4	2.9
Average number of farmers per tertiary canal in the sample	9	10	10	11	4
Average proportion of non-resident farmers per tertiary canal in the sample	18%	30%	12%	19%	5%

[a] Source: survey data, land register of the Office du Niger irrigation scheme

Data collection and analysis

The bulk of the data for this study are drawn from a questionnaire survey on strategies of water management at the tertiary level. The questionnaire contained a structured list of open questions in which farmers were asked to describe and evaluate the organization of water allocation and maintenance of the tertiary canal. The interviews further assessed difficulties related to water allocation experienced by other farmers of the tertiary canal, so that a diagnosis at the level of the tertiary canal could be made. When farmers answered that they experienced collective action problems with water allocation or maintenance, a follow-up question asked what they could do in order to alleviate those problems or prevent them from occurring. Another question, asked to all farmers, assessed which solutions they thought would work in order to improve farmers' water management in general. For detailed information on the questionnaire survey, see Keita (2003). Content analysis was used to analyze the questionnaire and categorize answers (Miles and Huberman, 1994). Additional information was gathered through field observations and informal discussions with farmers, water guards and functionaries of the central management. Data on group characteristics at the level of the tertiary canals were obtained from the land register of the Office du Niger and water guards. The survey was conducted from June to October 2003.

Table 4.2 Overview of differences in design and operation of the various types of infrastructure

Type of infrastructure	Properties
Original Retail	Tertiary intakes over-dimensioned with respect to peak water demand
KfW	A multiple of 7 field canals per tertiary canal in order to facilitate water allocation following a weekly rotation
World Bank	No specific features

Data analysis was performed at two levels. Rules-in-use were analyzed at the level of the tertiary canal (n = 59). When more than one farmer of a particular tertiary canal was interviewed, information was pooled and uniformized. The experience of problems was analyzed at the individual level (n = 89). Descriptive statistics are generated for the sample, and extrapolated to the research population based on respectively the total number of tertiary canals and farmers per type of infrastructure within the three zones under study. Relations between the application of rules and the experience of problems were assessed with Pierson chi-square tests. The same test was used to appraise differences between types of infrastructure regarding occurrence of rules and experience of problems.

4.4 Results and discussion

Rules on water allocation

Results show that on only 30 % of the tertiary canals from the sample, clearly defined water allocation rules are devised (29 % of the research population). Farmers mentioned a variety of rules in the interviews, such as a rotation between upstream and downstream groups of field canals and preferential access to water for plots that are difficult to irrigate. A fixed rotation scheme between individual field canals on a weekly basis is rarely applied. The application of rules is often flexible and frequently discontinued in periods of low water demand. On the other 70 % of the canals, farmers did not establish rules on water allocation, so that everyone can irrigate at any moment. Informal consultation between farmers however sometimes takes place in order to limit the number of farmers irrigating simultaneously or to prevent conflicts.

Next, 20 % of the interviewed farmers reported to have personally experienced regular problems due to fellow farmers' behavior (17 % of the research population). These problems fall into three categories. The first category consists of fellow farmers impeding the water flow during irrigation, such as the closing of the gates of field canals or the tertiary canal. Farmers would then be obliged to continue irrigation later on or to guard their plots continuously while irrigating in order to prevent those actions. The second category comprises the violation of rules by fellow farmers, causing one's irrigation program to be disturbed. A final category applies to farmers with plots that are difficult to irrigate and for which some coordination between farmers is necessary but impossible to achieve.

Further tests show that no association exists between the application of rules and the experience of problems (Table 4.3). Indeed, rules are often not devised even when problems do occur, and moreover establishing rules is no guarantee for solving problems. A diagnosis at the level of the tertiary canal further clarifies these results (Table 4.4). Clearly defined rules on water allocation are useful as they enhance the predictability of the water supply as to quantity and timing (Ostrom *et al.*, 1993). However, when water supply is plentiful with respect to demand and access is easy for all plots, the probability that irrigation activities of different farmers will hinder one another is small. Flooded rice has the additional advantage that water can be stored in the basins, so that the timing of irrigation matters less. From the interviews, it appeared that on 83 % of canals without rules, none of the farmers experiences any problems. In that case, there is indeed no need to establish rules. Possible problems are easily resolved through informal consultation. However, on 17 %, establishing rules would have been useful at least for some farmers, but did not succeed. On the other hand, the establishment of clearly defined rules is no guarantee for avoiding difficulties. Of the canals with rules, only about half are successful in avoiding collective action problems. In the other cases, existing rules cannot avoid those, most often due to violation by some farmers. Indeed, formal monitoring and sanctioning mechanisms lack completely on all canals and there is no person or structure with the authority to establish them.

Table 4.3 Association of the experience of problems with the application of clearly defined rules related to water allocation at the level of individual farmers

Application of clearly defined rules	Experience of problems		Total
	Yes	No	
Yes	26 % (8)	74 % (23)	100 % (31)
No	16 % (9)	84 % (49)	100 % (58)
Total	17	72	89
Pierson chi-square value = 1.384; df = 1			
Significance = 0.239			

Table 4.4 Association of the experience of problems with the application of clearly defined rules related to water allocation at the level of the tertiary block

Application of clearly defined rules	Experience of problems		Total
	Yes	No	
Yes	44 % (8)	56 % (10)	100 % (18)
No	17 % (7)	83 % (34)	100 % (41)
Total	15	44	59

Rules on maintenance

Rules on maintenance concern timing and effort required from each farmer. Most frequently, individual farmers clean a section of the canal bordering their plot. The size of this section is then defined based either on equal effort of all farmers, or in proportion to the size of the plot on the canal. In rare cases, farmers maintain the whole irrigation canal collectively. The timing of maintenance can be one particular day or a period of days defined according to the cropping season. It is important that maintenance is done in the same period on the whole canal. Indeed, the parts of the canal not yet maintained are a bottleneck for the downstream parts, and serve as a source for aquatic plants to reinvade the whole canal. Both rules are thus complementary. On 24 % of the tertiary canals from the sample, rules are devised on both aspects (27 % of the research population). On another 61 %, only rules on the effort required by each farmer are devised (59 % of the research population). It appeared however from the interviews that when comparing answers of farmers from the same tertiary canal, there is often no consensus on the concrete arrangements prescribed by the rules. When no rules are applied, decisions on whether and when to carry out maintenance are left to individual farmers.

Next, 43 % of farmers from the sample (equally 43 % of the research population) are dissatisfied about maintenance because the time spread of maintenance by different farmers is too big, or because of shirking by fellow farmers. Hence, even though rules are more frequent for maintenance than for water allocation, more farmers are dissatisfied on the topic. Since fellow farmers frequently shirk their maintenance duties, they have to either carry out the part of those farmers in addition to their own, or suffer the consequences of insufficient maintenance. In the latter case, they moreover see the result of their own efforts dissolved since neighboring canal parts are not maintained. Many farmers said to be discouraged by this and therefore stopped maintaining their own part. Especially non-resident farmers are accused of systematically shirking their maintenance duties and as such discouraging others. It must be noted however that farmers have often a different perception of the importance of regular maintenance, especially since it has little impact on flow rates in the short term when infrastructure is recently rehabilitated. For that reason, some farmers are dissatisfied, even though the maintenance level is sufficient in the view of others and vice versa.

Table 4.5 Association of the experience of problems with the application of clearly defined rules related to maintenance

Application of clearly defined rules	Farmers' dissatisfaction		Total
	Yes	No	
On both timing and effort required	16 % (4)	84 % (21)	100 % (25)
On effort required only	53 % (28)	47 % (25)	100 % (53)
No rules	55 % (6)	46 % (5)	100 % (11)
Total	38	51	89
Pierson chi-square = 10.138; df = 2			
Significance = 0.006			

Farmers' dissatisfaction is significantly related to the application of rules on maintenance (Table 4.5). More specifically, when rules on both timing of maintenance and effort required by each farmer are applied, fewer problems are cited. On the other hand, problems are about as frequent on canals with only rules on effort required are in use and canals with no rules at all. Again, further analysis of the interviews explains the results. As with water allocation, virtually no formal monitoring and sanctioning mechanisms are in place to enforce the rules in use. Instead, rules on the timing of maintenance have been abandoned when they were too often broken. This means that the rules remain in place in just those cases when maintenance is duly carried out by all farmers and everyone is satisfied. Creating rules on both timing and effort required will thus not guarantee more farmers satisfaction. On the other hand, rules on the effort required from each farmer remain more often in place, despite frequent violation. As stated above, this does not automatically lead to dissatisfactions since not all farmers attach the same importance to regular maintenance. In a limited amount of cases, farmers are dissatisfied about maintenance, without being able to establish rules.

The impact of the type of infrastructure on farmers' rules

The type of infrastructure is significantly related with the occurrence of clearly defined rules on water allocation (Table 4.6). In particular, on canals of the KfW type (village Banisiraela), rules are more frequently applied than elsewhere and usually imply some weekly rotation schedule. Engineers of the KfW type wanted to facilitate the organization of a rotation schedule on a weekly basis by designing canals such that each has a multiple of seven field canals. Their strategy has been successful in the sense that it favors the establishment of rules on water allocation. However, no such link exists with farmers' experience of problems, which is more equally divided over the types of infrastructure (Table 4.6). This means that a particular layout of the irrigation infrastructure can indeed promote organization of water allocation, but cannot guarantee the success of this organization for solving collective action problems. Another noteworthy observation is the average scores of the Arpon type for both the occurrence of rules and farmers' experience of problems. Whereas the other sponsors undertook a costly rehabilitation using expensive materials and machinery in order to allow a superior water control, the philosophy of Arpon was to work with cheap and locally constructed materials and have farmers participate in the rehabilitation works. In addition, they used tertiary canal intakes which farmers manipulate themselves. As such, they wanted to favor farmers' sense of ownership and increase their command over water supply. Despite differences in philosophy and cost of the rehabilitation, there is an impact on neither the occurrence of rules nor farmers' experience of problems.

Table 4.6 Application of clearly defined rules and experience of problems on water dsitribution by type of infrastructure

Type of infrastructure	Application of clearly defined rules			Experience of problems		
	Yes	No	Total	Yes	No	Total
Original Retail	0	100 % (12)	100 % (12)	15 % (3)	85 % (17)	100 % (20)
Arpon	40 % (6)	60 % (9)	100 % (15)	20 % (2)	80 % (16)	100 % (20)
KfW	73 % (8)	27 % (3)	100 % (11)	21 % (4)	79 % (15)	100 % (19)
World Bank	33 % (4)	67 % (8)	100 % (12)	26 % (5)	74 % (14)	100 % (19)
Not rehabilitated	0	100 % (9)	100 % (9)	9 % (1)	91 % (10)	100 % (11)
Total	18	41	59	17	72	89
	Pierson chi-square = 19.150; df = 4 Significance = 0.001			Pierson chi-square = 1.628; df = 4 Significance = 0.804		

Table 4.7 Application of clearly defined rules and farmers' dissatisfaction on maintenance by type of infrastructure

Type of infrastructure	Application of clearly defined rules				Farmers' dissatisfaction		
	Timing + effort	Effort	None	Total	Yes	No	Total
Original Retail	0	83% (10)	17% (2)	100% (12)	95% (19)	5% (1)	100% (20)
Arpon	13% (2)	67% (10)	20% (3)	100% (15)	35% (7)	65% (13)	100% (20)
KfW	27% (3)	67% (7)	9% (1)	100% (11)	16% (3)	84% (16)	100% (19)
World Bank	33% (4)	50% (6)	17% (2)	100% (12)	21% (4)	79% (15)	100% (19)
Not rehabilitated	56% (5)	33% (3)	11% (1)	100% (9)	45% (5)	55% (6)	100% (11)
Total	14	36	9	59	38	51	89
	Pierson chi-square = 10.97; df = 8 Significance = 0.204				Pierson chi-square = 32.141; df = 4 Significance < 0.001		

Differences in the application of rules on maintenance among the types of infrastructure are not significant (Table 4.7). It appears though that in the not rehabilitated type, rules on both timing and effort required for maintenance are relatively more frequent, which is still a striking result. Contrary to water allocation, rehabilitation of whatever type could not favor the organization of maintenance, not even the Arpon type, which nonetheless tried to enhance farmers' sense of ownership. On the other hand, farmers' dissatisfaction differs significantly over the types, with particularly high levels for the Original Retail type (Table 4.7). These can be explained for a large part by the particular policy of the water guard operating in the corresponding village from the sample. In order to force farmers to take on their maintenance duties, he locks the intake of all tertiary canals where he redeems the maintenance level unsatisfactory at the beginning of the main rice-growing season, so that shirking by fellow farmers is always problematic. This policy is however not official nor common. It is neither representative for the type of infrastructure.

Impediments to successful organization of water management

Thanks to an abundant water supply and oversized canals, problems related to water irrigation and infrastructure maintenance are rather rare. When they do occur, it appears that many farmers groups have been unable to devise, monitor and enforce rules to resolve them. Some possible impediments to successful organization of water management at the tertiary level are investigated by looking at the strategies adopted by farmers in order to alleviate collective action problems or prevent them from occurring. Subsequently, farmers' ideas to improve water management in general are discussed.

With respect to water allocation, some farmers have adopted individualistic strategies to reduce difficulties. They include advancing or postponing the sowing and planting date with respect to their neighbors in order to spread irrigation requirements, lowering the rice basins or reshaping the irrigation infrastructure so as to divert more water to their plots. These individualistic strategies do not only come to a personal cost but also inflict additional problems on fellow farmers. Furthermore, they offer no solution to every problem, and none exists with respect to maintenance. Very few farmers (less than 8 % of those citing problems) said they tackle fellow farmers about the problems they create, even though they admit they do not always succeed in convincing them to change their behavior. Moreover, by doing so, conflicts often arise. Most farmers however say they can do nothing to solve their problems, since they have no influence over their colleagues and want to avoid conflicts (see Box 4). This leads us to a first possible impediment to successful organization of water management in the area. Peer pressure, which can be a very powerful enforcement instrument (Aggarwal, 2000), is often ineffective. Especially non-resident farmers are immune to it, as they share no other activities with the farmers of the tertiary canal.

As to the general improvement of water management, only 14 % of the farmers considered more coordination of individual decisions and actions desirable. Another solution often proposed is that the central management defines and enforces individual responsibilities, not themselves. This is a remarkable result, since one of the main goals of the management reforms in the Office du Niger irrigation scheme was exactly to transfer responsibilities towards farmer groups. A second impediment might thus be the incomplete mentality shift towards assuming collective responsibility.

4.5 Conclusions and perspectives

Twenty years after the first reforms, farmers' water management is still immature. Indeed, clearly defined rules on water allocation and maintenance at the tertiary level are difficult to establish when necessary, and once established difficult to enforce. Despite attempts of engineers to enhance organization and motivate farmers for water management tasks through specific methods of rehabilitation, the resulting type of infrastructure has little impact on farmers' ability to devise, monitor and enforce rules to resolve possible collective action problems. Since water supply is abundant and the infrastructure recently rehabilitated in a large part of the irrigation scheme, the absence of organization of water management at the tertiary level does not necessarily lead to problems. Survey results have shown that some farmers on some tertiary blocks do have complaints about water allocation or maintenance, which shows that organization does not always arise spontaneously when needed. The amount of problems will probably multiply as water becomes scarce and the infrastructure deteriorates over time. The current situation is therefore not redeemed sustainable in the long term.

The historical and socioeconomic conditions of the irrigation scheme do not favor collective action. Indeed, two major impediments seem to be the ineffectiveness of peer pressure among farmers and their incomplete mentality shift towards assuming collective responsibility. In order to cope with problems ensuing from the lack of coordination, farmers rather adopt individualistic strategies that come at a personal cost and often exacerbate fellow farmers' problems. Measures of sensitization and group empowerment accompanying the process of management transfer will therefore be desirable. In part III of this dissertation, tools to support this process are presented.

Box 4 Conflicts on water management

Social peace is an important value among farmers in the Office du Niger irrigation scheme and for farmers, “good” water management implies avoiding conflicts (Bastiaens, 2005). Therefore, the occurrence of conflicts on water management at a tertiary block level seemed an appropriate performance indicator. Farmers however do not easily report their involvement in a conflict, as it is considered embarrassing. Despite considerable attention to question wording (for example, “conflict” was replaced by the softer “misunderstanding”), a closed question survey to allow quantification underestimated the number of conflicts (see Appendix 2). In several other series of interviews, the subject was however addressed in a qualitative way, so that insights were gained on how and when conflicts arise. The immediate cause is mainly competition over irrigation water. In particular, the presence of topographic differences within a tertiary block complicates water allocation, as farmers whose plot lies in a depression can easily divert all available irrigation water. A supply crisis is another typical moment for conflicts. Some farmers react individualistically and close their irrigating neighbors’ field canal on the sly to secure more water. Some are even said to “steal water at night”, i.e. irrigate with water from a neighbor’s field. On tertiary blocks where such practices are commonplace, farmers sometimes camp for days or weeks in a row next to their plot to get enough water. Occasionally, conflicts escalate in violence. Too much water can also lead to conflicts. Negligent farmers leave their field canals ajar for several days, or irrigate with the drainage outlet open. As such, they might flood neighboring fields and fill the tertiary drain, exacerbating drainage problems.

In the eyes of farmers, the root cause of conflicts lies in attitude: incomprehension, impatience, lack of respect and individualism, which they connect to farmers’ increasing liberty of action. Next, the absence of rules and hierarchy for water management make rights and obligations unclear, leaving room for disagreement. Nevertheless, conflicts appear to be rather rare. Farmers avoid them and rather swallow their fellow farmers’ individualistic behavior than tackle them about it. Moreover, on most tertiary blocks reigns an understanding between farmers that allows them to solve their problems reasonably. Most conflicts do not linger for long anyway. As one farmer reported: “A couple of days later, when water arrives again [after a supply disruption], everyone will be ashamed.”

Chapter 5

Performance, prejudice and collective action

Abstract[1]

Increasing irrigation efficiency has always been high on the agenda of policy makers. Despite some 'social' experiments, whereby important parts of management were carried over to the farmer level, results often remained disappointing. This chapter explores why this came about for the case of the Office du Niger irrigation scheme. Since Irrigation Management Transfer, farmers are responsible for the tertiary level, but collective action for water management remains underdeveloped. From the stakeholder analysis, it appears that the central management wants to increase irrigation efficiency through fully-fledged collective action, whereas farmers value the latter only when it favors easy irrigation. In this chapter, the relation between collective action and performance is tested through a field study on a sample of 36 tertiary blocks. Results indicate that only collective action at the intake of the tertiary canal, currently implemented on less than a third of the tertiary blocks, increases irrigation efficiency. Collective action for water allocation is implemented within almost three quarters of tertiary blocks and effectively reduces irrigation problems. However, if they lack the necessary social capital, not all farmers can establish collective action when needed. Based on this analysis, the chapter proposes a mix of incentives and measures to resolve the conflict between farmers and the central management to their mutual benefit.

5.1 Introduction

The implicit assumption of Irrigation Management Transfer (IMT) in the Office du Niger irrigation scheme was that, given the responsibility, farmers would automatically invest in

[1] This chapter is adapted from: Vandersypen, K., Verbist, B., Keita, A. C. T., Raes, D., and Jamin, J.-Y. (Submitted). Performance, prejudice and collective action. Water Resources Management.

“rational water management” and establish the necessary organization to resolve collective action problems. With IMT, collective action was introduced on some tertiary blocks and for some aspects of water management. When it exists, it is organized in a very informal way and depends largely on farmers’ awareness of the benefits of collective action and the capacity of one or more group members to establish a consensus on certain rules or activities (Chapter 4). However, in most cases, the ample water availability has led to a situation without coordination of water supply and demand or the cropping calendar and poor infrastructure maintenance (Chapter 3 and Chapter 4). To promote collective action, the central management developed several projects with international donors to sensibilize farmers and to mould them in Water User Associations, albeit with limited success until now (Chapter 7).

From the stakeholder analysis, we know that the failure of such policies is strongly linked with the divergence in objectives and strategies of farmers and the central management. In this chapter, the relation between collective action and performance is evaluated in the real world through a field study. Therefore, performance indicators are constructed reflecting stakeholders’ objectives as defined in the stakeholder analysis (Chapter 2). Combining an understanding of stakeholders’ objectives and strategies on the one hand, and real world relations on the other hand, it proposes recommendations for solving the conflict between stakeholders to their mutual benefit. As such, this chapter makes a plea for research taking part in the process of irrigation management in particular, and natural resources management in general, as it can play a beneficiary role by providing negotiation support to the various stakeholders.

5.2 Materials and methods

For the field study, variables were selected based on the stakeholder analysis and measured on a sample of tertiary blocks (see Chapter 3). A purposive sampling method was applied whereby nine villages were selected in the rehabilitated area of the administrative zones Niono and N’Debougou containing the complete range of old and recently rehabilitated areas. Summary data on the selected villages and samples taken are presented in Table 5.1. In each of the villages, four tertiary blocks were picked randomly, so that the total number of sampled tertiary blocks is 36. Together, they contain 299 plots. Data collection for the calculation of the indicators was done for the growing season of 2004. Triangulation methods were used to validate and complete data through informal interviews with 40 plot-holders from the sub-sample and regular observations on the field. Informal interviews and observations took place throughout 2004 and 2005. Associations between the variables are tested using Spearman correlation coefficients and one-way ANOVA tests. Statistical analyses were performed with the SPSS computer package. The following sections describe the calculation procedures and data collection methods for each of the variables. These variables concern (1) performance indicators corresponding to stakeholders' objectives and (2) indicators for collective action.

Table 5.1 Summary data on the selected villages and sample (Number between brackets represent data for the sampled tertiary blocks)

Village	Secon-dary canal	Number of tertiary blocks		Irrigated surface (ha)		Number of plot holders		Number of plot holders per tertiary block		Average plot size (ha)	
Moussa Werè	KL0	26	(4)	479	(105)	94	(45)	3.6	(11.3)	5.1	(2.3)
Kouyan							(28)				
Peguena	KO1	8	(4)	150	(74)	81		10.1	(7.0)	1.9	(2.6)
Coloni	N1	33	(4)	621	(62)	263	(45)	8.0	(11.3)	2.4	(1.4)
Médina	G5	26	(4)	509	(113)	188	(49)	7.2	(12.3)	2.7	(2.3)
Siguivoucé	S6	25	(4)	653	(62)	203	(23)	8.1	(5.8)	3.2	(2.7)
Fassun	S8	17	(4)	300	(75)	103	(28)	6.1	(7.0)	2.9	(2.7)
Medina-Coura	B3	34	(4)	759	(58)	208	(20)	6.1	(5.0)	3.6	(2.9)
Tiemedeli-Coura	B5	34	(4)	451	(65)	208	(34)	6.1	(8.5)	2.2	(1.9)
Kanasakko	BE3	20	(4)	239	(49)	222	(27)	11.1	(6.8)	1.1	(1.8)
Total for sample villages		223	(36)	4161	(663)	1570	(299)	7.0	(8.3)	2.7	(2.2)
Total for rehabilitated area of Niono and N'Debougou		1042		20 736		6184		5.9		3.4	

Performance indicators

Irrigation efficiency

Irrigation efficiency (P_f) compares the volume of water required to the water delivered during a certain period at the level of the tertiary block. It measured using the indicator proposed by Molden and Gates (1990). Calculation methods are explained in Chapter 3.

Agricultural production

Agricultural production in tons of rice harvested per hectare is measured at plot level, from which a weighted average per tertiary block is calculated. Since farmers know the number of bags of paddy harvested on their field - one bag containing on average 75 kilos - agricultural production was assessed trough a questionnaire survey (see Appendix 2) on the total cultivated surface and the total number of bags harvested. Agricultural production was evaluated for the total number of plots within the sample of tertiary blocks. In the process of harvesting, some of the rice is lost during transportation and threshing. This method thus probably implies an underestimation of agricultural production compared to the method applied by the central management, which samples unharvested rice. However, it is considered precise enough in the scope of a comparative analysis.

Ease of irrigation

With no flow measurement structures available at plot level, conventional irrigation performance indicators based on flow data are not suitable for measuring the ease of irrigation. An obvious alternative is to assess directly the opinion of farmers (Svendsen and Small, 1990). From the survey with 43 farmers in the frame of the stakeholder analysis (see Appendix 3), it appeared that the ease of irrigation from farmers' perspective encompasses two distinct aspects. The first is the occurrence of irrigation problems, and the second is the application of strategies to mitigate those problems. For each of these aspects, different features can be distinguished, consisting in the various causes of irrigation problems and the various strategies respectively.

Farmers were surveyed using a closed-question survey with scaled responses (see Appendix 2). The variable is derived from an overall assessment of the ease of irrigation, the occurrence of irrigation problems and the application of strategies to mitigate them. An overall assessment of the ease of irrigation was obtained through the question 'Has irrigation been easy?' accompanied by a three-point Likert answer scale (from 'always' = 1 to 'never' = 3) (Likert *et al.*, 1993). Next, both quantity (how often and how long) and intensity (degree of disturbance) of the inconvenience for each of the features composing irrigation problems and strategies applied were rated on a three-point Likert scale (from 'high' = 2 to 'low' = 0). Ease of irrigation is then computed as:

$$\text{Ease of irrigation} = \text{Overall assessment} + \frac{\sum_i \text{quantity} \cdot \text{int ensity}}{\text{max imal score}}$$

and ranges from 1 to 4 with lower scores corresponding to irrigation being easier. The indicator at tertiary block level is an arithmetic average of individual scores.

Ease of irrigation was evaluated for a sub-sample of 150 plots within the sampled tertiary blocks. Plots were selected randomly and at least one third of plots per tertiary block was sampled. Two trained interviewers administered the survey and contacted the responsible farmer for each plot of the sub-sample for a one-to-one interview. A first version of the questionnaire was developed in French and translated in the local language, Bambara, using the translation-back-translation method (Brislin *et al.*, 1973). This version was adapted after a testing phase using the techniques described in Foddy (1993). Several formulations of key questions were included in the questionnaire so that answers could be crosschecked for inconsistency. In eleven cases, inconsistencies were detected and these results from the questionnaire were excluded from further analysis.

Indicators for collective action

Coordination of the cropping calendar

Coordination of the cropping calendar is evaluated by the standard deviation of transplanting dates. Through fortnightly monitoring of the transplanted surface, the transplanting date of each basin is estimated. Standard deviations are weighed against the surface transplanted for each date. This coordination would spread (and thus lower) peak demands over time when transplanting the rice into the paddy fields, while avoiding long intervals in transplanting for neighboring fields, as they might lead to conflicts between irrigation and drainage activities.

Maintenance of tertiary infrastructure

The maintenance level of tertiary irrigation canals is evaluated through fortnightly observations throughout the growing season. Farmers generally clean the canal section adjacent to their field independently from each other, so maintenance levels can differ considerable in time and space. Therefore, every canal section in between two field canals, the maintenance level was scored on a scale from 1 (good) to 3 (bad). Scores were then averaged for the canal and for the growing season to obtain a single result.

Water allocation within the tertiary block

Since most of the time, water availability in the tertiary canal covers aggregate irrigation demand, free access to water is the common practice. In periods of peak aggregate water demand or water crisis at the secondary level, rules are sometimes devised to coordinate water allocation and avoid crowding. In a more general way, on tertiary blocks where allocation rules are successfully applied, farmers accept the principle that their access to water can be restricted in favor of the common interest, which facilitates coordination of water allocation also outside periods of peak demand. On some tertiary blocks where rules on water allocation are not (effectively) applied, informal consultation to resolve irrigation problems on the spot is however commonplace. Through this consultation, temporary agreements can be made between two or more farmers of a tertiary block regarding water allocation. Collective action concerning water allocation is therefore assessed through a categorical variable containing three ordered categories. The first category corresponds to the application of strict rules on water distribution, taking into account compliance and the availability of sanctions to ensure their effectiveness. The second category corresponds informal consultation being commonplace, leaving tertiary blocks with neither rules nor consultation in the third category. The indicator is evaluated through group discussions and crosschecked with informal individual interviews and regular observations on the field. Separate group discussions with three to six participating farmers took place per tertiary block. Discussions were led by the researchers using a flexible interview guide (see Appendix 3) and assisted by an interpreter.

Coordination of water supply and demand at tertiary block level

Coordination of water supply and demand at tertiary block level consists in adjusting water supply to the tertiary block at all moments to aggregate demand. When such coordination takes place, usually an influential farmer has taken the responsibility to collect information on water demand of fellow farmers. Next, he opens and closes the tertiary intake according to aggregate demand. Alternatively, farmers inform a responsible person on their irrigation activities, so that the latter can estimate the appropriate opening of the tertiary intake. The collective action indicator is a categorical variable indicating whether yes or no, coordination takes place and is based on results from group discussions (see Appendix 3), crosschecked with informal individual interviews and regular observations in the field.

5.3 Results and discussion

5.3.1 Results from the field study

Descriptive statistics for the indicators of collective action and performance

Table 5.2 presents descriptive statistics of the indicators for collective action and performance. Average irrigation efficiency is 0.59, a value that is considered low according to the standards put forward by Molden and Gates (1990). Variability in irrigation efficiency is however large, ranging from 0.23 to 0.87 and with a standard deviation of 0.18. Average agricultural production as reported by farmers is 3.9 t/ha, which is well below the objective of 6 t/ha often suggested in project reports (Aw and Diemer, 2005). Rather than water, an inefficient input market (for fertilizer, pesticides, …) is blamed for these low yields (see Box

5). The standard deviation of average production at tertiary block level is only 0.7 t/ha, but hides the important variability in production between individual farmers: Agricultural production ranges from 0 t/ha (for two farmers whose crop was flooded and lost due to excessive water supply to their tertiary block) to 6.5 t/ha and shows a standard deviation of 1.2. Ease of irrigation at tertiary block level has an average score of 1.5, implying that on many tertiary blocks, irrigation is always easy for all farmers. The variable has a standard deviation of only 0.5, indicating that when farmers are confronted with irrigation problems, it affects only a few per tertiary block. For the sample of tertiary blocks, no significant correlations exist among the three performance indicators.

Table 5.2 Descriptive statistics of the variables (n = 36)

Indicator	Average	St. Dev	Min.	Max.
Irrigation efficiency - average [St. Dev]	0.59	0.18	0.23	0.87
Average agricultural production - average (t/ha)	3.9	0.7	2.5	5.7
Average ease of irrigation[a] - average (t/ha)	1.47	0.46	1.00	2.79
Standard deviation of planting dates - average (days)	18	6	6	32
Tertiary infrastructure maintenance[b] - average	1.62	0.35	1.00	2.06
Water allocation within the tertiary block				
No consultation	18 %			
Informal consultation	53 %			
Strict rules	19 %			
Coordination of water supply and demand				
Yes	31 %			
No	69 %			

[a] Scores range from 1 (very easy) to 4 (very difficult)
[b] Scores range from 1 (good) to 3 (bad)

The period in which transplanting takes place on a tertiary block ranges from one to more than three months. In an extreme case, some fields were already being harvested while others were at the stage of being transplanted. On most tertiary blocks, transplanting takes place within two months, with often a peak during ten to twenty days. This translates in an average standard deviation of planting dates of 18 days (Table 5.2). Even though four fifths of the farmers transplant within the limits prescribed by the central management (Office du Niger, 2005), this situation contrasts sharply with the period before IMT. Back then, all farmers of a village were obliged to start the growing season at the same date prescribed by the central management for practical reasons. In the stakeholder analysis, it was found that the central management as well as some farmers still consider this the norm. For them, the current situation appears quite bad. The average score for tertiary infrastructure maintenance is 1.62. For the central management, who wants to preserve canals in perfect conditions, only a score close to 1.0 would be acceptable. Current maintenance levels thus confirm their view of neglect of maintenance. At 0.35, the standard deviation is rather small, with scores ranging from 1.0, for the perfectly maintained canals, to only 2.06, whereas the maximum score is 3.0. A good score for tertiary infrastructure maintenance does however not always reflect farmers' efforts. Some canals have not yet been colonized by certain weeds, so that regular maintenance is not necessary. Rules on water allocation within the tertiary block are effectively applied on about one fifth of tertiary blocks from the sample, and on half of them, informal consultation is commonplace. On the other tertiary blocks, water allocation is not coordinated at all. Finally, on about one third of tertiary blocks, coordination at the tertiary intake takes place. No significant correlations exist among the indicators for collective action.

Box 5 Causes of disappointing yields

Even though irrigation problems are an issue for many farmers, they seldom result in water stress and yield decline. Currently, the biggest bottleneck for good yields are constraints in the input markets. Because of the scarcity of credit and shortage and high price of mineral fertilizer, many farmers cannot apply the required dose. Survey results[1] indicate that three quarters of farmers were not satisfied with their production, and of those, more than 40 % reported a lack of fertilizer as the main cause of disappointing yields (Figure 5.1). The average production of this group was 3.6 t/ha, well below the total average of 3.9 t/ha. The magnitude of the fertilizer problem from farmers' point of view was further demonstrated by their spontaneous remarks throughout and after interviews. Indeed, many asked to take note of the dysfunctional markets or report the problem to the central management. Compared with this, water management does not have a big impact on production. Flooding can cause serious yield loss, but is exceptional. Next, respectively 15 % and 10 % of farmers dissatisfied with yields cited drainage problems at harvest and water stress as main causes of disappointing yields. Still, they reported a production of 3.8 t/ha on average. Consequently, under the present circumstances, improving water management will not result in an increase of total output. Only when water becomes scarce, a direct link between water management and yields might appear.

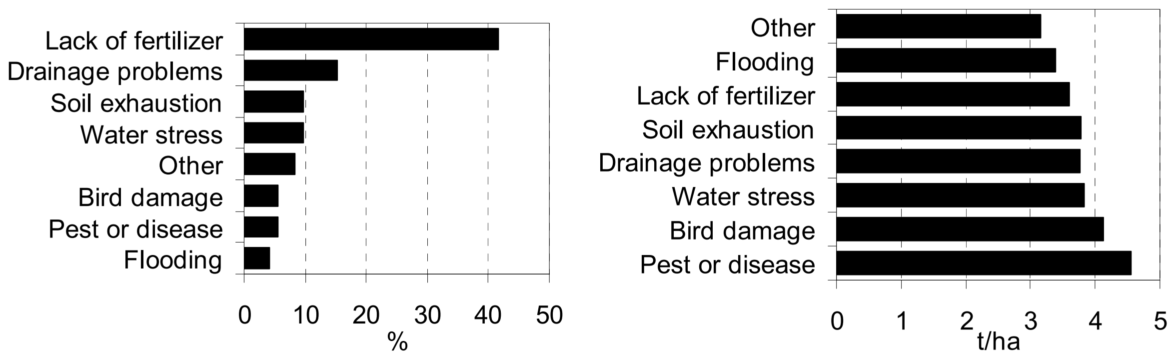


Figure 5.1 Main cause of dissapointing yields as perceived by farmers (left) and average production according to farmers' perception of the main cause of dissapointing yields (right)

1 The survey (see section 5.2 and Appendix 2) asked whether farmers were satisfied with their rice production, and if not, which was the most important cause of disappointing yields.

The relation between collective action and performance

Average agricultural production is not significantly linked with any of the collective action variables, indicating that it does not make a difference for actual yields. Efficiency is linked only with coordination at the intake of the tertiary block (one-way ANOVA: $F_{1,34} = 5.067$, $p = 0.031$). From Table 5.3 it becomes clear that for tertiary blocks with coordination at the intake, average efficiency amounts to 0.68, whereas on the other tertiary blocks, it is only 0.54. Soil properties, topography and individual farmers' practices should explain the remaining variation. Coordination of water demand at the tertiary blocks can thus significantly increase irrigation efficiency and as such allow an expansion of the irrigated area. Currently, such coordination takes place mainly on lower lying tertiary blocks risking drainage problems at harvest. As they may not be able to evacuate the water diverted to their tertiary block, they try to control the inflow. On a few tertiary blocks, the prestige of rational water use is the only motivation.

Table 5.3 Effect of the coordination of water demand on irrigation efficiency

Coordination of water supply and demand	Number of tertiary blocks	Irrigation efficiency
No	25	0.54
Yes	11	0.68
Total	36	0.59

Table 5.4 Influence of strict rules and informal consultation among farmers on ease of irrigation

Water allocation within the tertiary block	Number of tertiary blocks	Average score for ease of irrigation[a]
No consultation	10	1.77
Informal consultation	19	1.36
Strict rules	7	1.35
Total	36	1.47

[a] Scores range from 1 (very easy) to 4 (very difficult)

Table 5.4 points to the fact that the more water allocation is regulated, the higher the score for ease of irrigation (one-way ANOVA: $F_{1,33} = 3.184$, $p = 0.054$). The immediate cause of irrigation problems is typically a temporary supply problem at the secondary level or the higher position of some plots, which makes them more difficult to irrigate. The root cause is however the absence of equitable allocation of the available water. Indeed, the rice crops' water requirements are largely covered by supply on about all tertiary blocks. Furthermore, none of the farmers from tertiary blocks with strict rules on water allocation ever suffers from severe irrigation problems, indicating that rules do provide an effective solution. Solidarity and peer pressure provide the necessary incentives when water allocation is regulated, but is insufficient on some tertiary blocks where irrigation problems remain unresolved.

The maintenance level has no relation with irrigation efficiency or ease of irrigation. Consequently, the current perception of the central management on the importance of maintenance is probably based on prejudices rather than facts. It must be added that tertiary canals have been vastly over-dimensioned compared to peak water requirements for reasons of canal construction. The flow rate being the product of velocity and the canal's wetted cross-section, a loss in velocity due to weed growth in the canal bed is thus negligible. Farmers' motivation for maintenance is indeed related to avoiding weeds and pests rather than hydraulics. With time, the canal banks however also degrade, making it difficult to fill the canal to its design level to dominate more elevated parts of the tertiary block. This process is too slow to be already measurable only about ten years after rehabilitation. Similarly, stretching of the cropping calendar has no impact on efficiency or ease of irrigation. Consequently, there is no hydraulic basis for tightening the coordination of the cropping calendar as far as irrigation is concerned. Stretching of the cropping calendar has however been observed to increase the probability of drainage problems, which results in increased production costs and/or loss of production and rice quality. In the Office du Niger irrigation scheme, about 40 % of farmers are confronted with them (Chapter 6).

5.3.2 Recommendations for solving the conflict between stakeholders

Insights in the mental models of stakeholders and real world relations between collective action and performance can lead to solutions that take into account the concerns of both parties. Three recommendations stand out. First, efforts to promote collective action should be well targeted. The mental model of the central management is prejudiced by an idealistic view on how water management should be, which leads it to promote fully-fledged collective action on all aspects. They furthermore attach special attention to maintenance, as it is a very visible indicator of management. Maintenance is however not (yet) linked with irrigation efficiency or agricultural production. Since labor input is an important variable for farmers, efforts to promote collective action will be more successful when targeted at just the most effective variable.

Second, incentives are needed for farmers to increase irrigation efficiency. Results from the field study show that significant improvements in irrigation efficiency can be achieved through collective action at the intake of the tertiary canal. Averting drainage problems can be a motivation, but is relevant for particular tertiary blocks only. Prestige is another driver and seems important enough within a few blocks. It will however not convince all farmers, especially as an increase in irrigation efficiency might limit the comfort level of irrigation and jeopardize those farmers with less than optimally located plots within a tertiary block. If irrigation efficiency is to be increased, other drivers need to be explored in consultation with the farmer groups. Measures that can be discussed and negotiated between the farmer groups and the central management are e.g. physically limiting water supply to the tertiary block or a quota system with a progressive price level according to their water consumption, whereby irrigation above a certain threshold is charged higher. It should be furthermore explored how farmers can get positive incentives to increase irrigation efficiency and make the expansion of the irrigated area possible, e.g. reductions in overhead cost of the irrigation scheme could be passed on to farmers of a certain tertiary block by reducing their water fee as a function of their irrigation efficiency. Another positive incentive could be that farmers who obtain a very high irrigation efficiency can qualify for access to extra land in the to be developed area. It would still need to be investigated to what extent this incentive would be interesting enough for farmers and to what extent it can be justified towards would-be farmers on the waiting list for access to an irrigated plot. Measuring water delivery to individual plots is currently impossible due to the physical layout of the irrigation scheme. Incentives (positive and negative) will thus inevitably have to be applied at the collective level.

Third, whatever the incentives put into place, farmers will need extensive training and extension. Indeed, they need to be made aware of the fact that the current situation of abundant water will cease to exist as the irrigation scheme expands further, but that they can avert the negative consequences of water scarcity by adopting the right practices to limit water loss and allocate water equitably. Next, training will be needed to familiarize farmers with these practices. Finally, in order to guarantee equitable water allocation among farmers when water will be scarcer, collective action on allocation should be promoted as well. Today, not all farmer groups succeed in engaging in collective action, even when irrigation problems occur. In those cases, farmers might be motivated to maintain the current over-supply of water to minimize irrigation problems, despite incentives for water saving.

5.4 Conclusions

In natural resources management in general, and irrigation in particular, policies to promote soil and water conservation do not always deliver the desired outcome. This chapter discusses the case of the Office du Niger irrigation scheme were IMT to farmers so far, has led to disappointing results in the eyes of the central management. Through the stakeholder analysis elaborated in Chapter 2, it was possible to clarify the conflicting strategies of the central management and farmers. Results from the field study now allowed testing the relation between collective action and performance in the real world. It appeared that collective action at the intake of the tertiary blocks can improve irrigation efficiency with at least 14 %, but is limited to 11 out of 36 tertiary blocks as site-specific factors and prestige are the only drivers. Collective action for water allocation is much better developed (26 out of 36 tertiary blocks). Indeed, mitigating irrigation problems, it leads to direct benefits for at least some farmers on the tertiary block. Even when needed, some farmer groups however do not succeed in establishing collective action. It also became clear that some mental models were flawed. In particular, maintenance, currently an important indicator for the central management, is not a good predictor for low irrigation efficiency or rice production. Similarly, tightening the coordination of the cropping calendar will yield no benefits for irrigation.

Only through a better insight in stakeholders' objectives and the cause-effect relationships of water management, better policies can be designed that go beyond prejudice. As farmers try to maximize returns to labor input, increasing irrigation efficiency can be achieved if their efforts are rewarded. Consequently, if direct benefits are lacking, incentives should be put in place. The search for the appropriate incentives will require several iterations whereby stakeholders can learn from the actual results of policies and adjust their mental models. Being more neutral and unbiased, researchers could play a beneficial role in accompanying this process.

Box 6 Cultivating all year round

Cultivating a second crop in the dry season is introduced as part of intensification. At first, certain tertiary blocks at the head of the secondary canals were assigned for double cropping, but as the practice became more accepted, farmers were allowed to grow a second rice crop or vegetables in their regular plots too. None of the 36 tertiary blocks from the sample described in Table 5.1 was originally destined for double cropping. Nevertheless, in about four blocks out of five, double cropping was practiced in 2005. Most of them combined rice with vegetables, the latter taking up around 15 % of the cultivated surface. Initially, short-cycle rice varieties were advised for the dry season. These varieties are sown in February and harvested in April to avoid the cooler months of December and January in which rice development slows down. Over the years, it became however popular to grow the same varieties as in the rainy season, which have to be sown as early as December. With the four-month cycle stretched by the cool temperatures, harvest still takes place in April.

From a short survey on the topic, it appeared that generally, farmers find that double cropping wears out the soil and might depress yields in the rainy season. Still, as it brings in some extra money to bridge the hunger gap striking at the start of the rainy season, it is considered favorable overall. The second rice crop implies however several negative externalities for neighboring farmers and is therefore a source of conflicts. Any delay in the harvest of the dry-season crop obviously hampers the planting of the rainy-season crop, which results in a dispersal of planting dates in the tertiary blocks. Consequently, periods for irrigation and drainage will then overlap. Furthermore, as tertiary irrigation and drainage canals are filled with water the whole year round, aquatic weeds proliferate more easily, increasing maintenance requirements. Finally, lateral seepage moistens neighboring fields, provoking weed growth and making land preparation a headache.

Only the well-off farmers are able to cultivate a second rice crop. First, you have to be well equipped, as people are reluctant to rent out their ploughs and oxen to work the land still wet after the rainy season. In addition, credit is not available for the second crop and fertilizers are hard to find. A solution is to rent out the land just for the dry season. Increasingly, the second rice crop is grown on rented land by entrepreneurial types, who practice farming as an extra. These constraints do not apply for vegetable farming, which as a rule is done by women and young adults. Here, the bottleneck is the output market. With no or few transformation done in the area, all produce arrives simultaneously and fresh at the market, which is quickly saturated resulting in low prices. Another constraint on further development of double cropping is water. In March, when the peak irrigation requirements of the dry season are reached, water availability in the Niger River reaches a low. The past few years, the Office du Niger already withdrew the maximum amount of water allowed under international treaties. Extracting water from the shallow water table might be an option but has not yet been investigated.

Chapter 6

Drainage problems in relation to water management

Abstract[1]

This chapter quantifies the impact of water management on the incidence of drainage problems in the Office du Niger irrigation scheme. The irrigation scheme faces perpetual drainage problems at harvest, which incur increased production costs as well as production and/or quality loss. The rice schemes discharge water into natural depressions and their filling-up poses an ultimate bottleneck to the disposal of drainage water. Results demonstrate that the principal causes of drainage problems are the saturation of the drainage system with excess irrigation water and the insufficient maintenance of the collector drains. Once the collector drain is no longer saturated, maintenance of the tertiary drains becomes important, while the disparity in harvest dates between adjacent fields always aggravates the drainage problem. Since the benefits of individual efforts often accrue to neighbors or are dissipated throughout the entire drainage system, water management practices related to drainage should be tackled at the collective level using Water User Associations as a platform.

6.1 Introduction

Inadequate drainage in irrigation schemes, and especially flooded rice schemes, is an important source of high groundwater tables, water logging, salinisation, and eventually yield loss (Smedema *et al.*, 2000; Konukcu *et al.*, 2006). Its root causes are insufficient drainage capacity on the one hand, and over-supply of drainage water on the other hand. Since most of the attention and funds usually go to irrigation, many irrigation schemes have deficient

[1] This chapter is adapted from: Vandersypen, K., Keita, A. C. T., Coulibaly, B., Raes, D., and Jamin, J.-Y. (2007). Drainage problems in the rice schemes of the Office du Niger (Mali) in relation to water management. Agricultural Water Management, 89, 153-160.

drainage systems (Smedema and Ochs, 1998). Furthermore, current irrigation practices often imply excessive water use, which unnecessarily increases the volume of water to be drained beyond the system's capacity (Wichelns, 1999; Datta and de Jong, 2002). The consequences of drainage problems are increasingly being acknowledged within the scientific community, but the focus remains very much on the technical relations between irrigation and drainage and their environmental consequences. However, in order to study drainage problems, its relation with water management practices has to be fully understood. This relation often has a social component, since the drainage facility is a public good. Indeed, it is costly to prevent farmers from discharging water in the drainage system, but everyone suffers the negative consequences of its saturation. Furthermore, many water management practices affecting drainage require cooperation between farmers. Coordination of the cropping calendar in flooded rice schemes and the use and maintenance of collective drainage infrastructure are typical examples. Water management practices at the collective level related to drainage have not yet been thoroughly studied. In order to formulate recommendations, the impact of water management practices on drainage problems is quantified in this chapter.

The Office du Niger irrigation scheme faces structural drainage problems (de Wilde, 1967; World Bank, 1979; Van der Walle, 1982; Malé, 1991; Keita, 2003). Moreover, recent rehabilitation of the irrigation scheme did not solve them. As in many other irrigation schemes, an inadequate drainage system in combination with excessive use of irrigation water is the root cause of the drainage problem. Water being abundant, labor input for water management is minimized by maintaining an over-supply of water in comparison to demand (Chapter 3), resulting in an overall irrigation efficiency of about 25 % (Vandersypen *et al.*, 2005). At the onset of the main growing season, which coincides with the rainy season, the soil is soaked and a water layer is established in the rice basins. As a result, the groundwater table rises close to surface level, leaving little room for water storage. Consequently, all excess water is conveyed to the drainage system, which discharges in natural depressions outside the irrigation scheme. The area being quite flat, the slope of the drainage canals is limited and the discharge diminishes as the depressions fill up with drainage water (Van der Walle, 1982; Hendrickx *et al.* 1986).

Besides the general risk of salinisation and alkalinization problems and water-borne diseases, there are also some direct effects for the fields suffering from drainage problems. Some already suffer from excessive flooding during the growing season, which negatively influences grain yield. Indeed, excessive flooding reduces seedling establishment after transplanting, diminishes tillering and induces adaptive strategies in the rice plants, such as extreme aerenchyma development and stem elongation (Anbumozhi *et al.*, 1998; Ito *et al.*, 1999). The drainage problem in the Office du Niger irrigation scheme is however most pronounced at harvest, when draining of the flooded fields before harvest is difficult or even impossible. At harvest, it is standard practice to deposit the harvested rice crop on the ground and sheave it a few days later. After several weeks of drying, the sheaves are assembled in a stack for threshing, using mobile threshing machines brought to the field. Depositing a harvested rice crop in wet or humid circumstances causes germination and/or considerable quality loss within a few days (Phillips *et al.*, 1988; 1989; Soponronnarit *et al.*, 1998). Consequently, when a field is harvested wet, the rice has to be evacuated to a dry place nearby, which involves a considerable higher labor input. In addition, day laborers, which are commonly hired at harvest to supplement family labor, demand up to 25 % more salary per day to compensate for the arduous work conditions. Next, the moisture content of rice harvested from a wet field being too high for storage, the rice needs to be dried. If not enough room is available near the field, threshing has to follow quite rapidly so that the paddy can be transported to the village for drying. Evacuation of rice from the field and threshing of wet rice involve grain loss. Furthermore, if drying is too slow, grain quality might still deteriorate as described above. If drying is too fast, milling yield reduces and the percentage of broken grains increases (Jodari and Linscombe, 1996; Imoudu and Olufayo, 2000). Drainage problems at harvest might have important financial consequences for farmers, both because of increased production costs and of a reduction in rice quantity and quality (see Box 7).

The root causes of drainage problems should be tackled at the scheme level, but management practices at the tertiary level might nevertheless also increase their incidence. Since the Irrigation Management Transfer, farmers are now collectively responsible for water supply to the tertiary block, maintenance of tertiary infrastructure and coordination of the cropping calendar. In many tertiary blocks, free-rider problems and the absence of functional rules to coordinate activities result in over-supply of water to the tertiary block, neglect of maintenance and disparity of planting and harvest dates Chapter 4). These are in turn assumed to exacerbate drainage problems (Keita, 2003; Boeckx, 2004), even though their precise impact is not known. Indeed, up until today, water management practices in the Office du Niger, as well as other irrigation schemes, have largely been studied from the perspective of irrigation rather than drainage. The goal of this chapter is therefore to assess the impact of management practices on the incidence of drainage problems at field level using statistical analysis and to formulate recommendations for improved water management.

6.2 Materials and methods

Drainage problems are studied at field level, the level of observation being the harvest unit. A harvest unit corresponds to several contiguous rice basins that belong to the same farmer and have the same planting and harvest date. A unit is considered to be confronted with drainage problems if, at the time of harvest, water remains in the basins as a uniform water layer or puddles covering at least 20 % of its surface.

Table 6.1 Descriptive statistics for the determinants of drainage problems at harvest

Variables	Average	St.Dev	Min.	Max.	Average if drainage problem occur	
					No	Yes
Harvest date	2/11	18 days	15/8	31/12	5/11	25/10
Maintenance collector drain	30 %				35 %	20 %
Disparity in harvest date with neighboring fields	43 %				34 %	58 %
Maintenance level tertiary drain (score from 1 (good) to 3 (bad))	2.20	0.39	1.00	3.00	2.80	2.24
Proportion of the tertiary block surface being drained in the same 10 days (%)	34	21	1	100	36	31
Excess irrigation during the decade before harvesting (m³/ha)	133	695	-1068	3876	156	92
Size of the harvest unit (ha)	0.91	0.80	0.08	11.87	0.94	0.84
Type of infrastructure						
Arpon type	40 %				35 %	47 %
Retail type	60 %				65 %	53 %
Year						
2004	42 %				38 %	49 %
2005	58 %				62 %	51 %

The independent variables used to explain the incidence of drainage problems concern the root causes at scheme level, water management practices at the tertiary level and characteristics of the measurement. The following sections explain how each of the independent variables is operationalized. Descriptive statistics of the independent variables are shown in Table 6.1. Apart from the independent variables included in the statistical model, several other aspects might influence the incidence of drainage problems. First, the drainage network functions as communicating vessels, so tertiary blocks situated in depressions, and within each tertiary block low lying fields, naturally have more difficulties with drainage than other tertiary blocks and fields. Second, the water layer to be drained at harvest varies considerably from one field to another, depending on farmers' water management strategies and land leveling (Klinkenberg *et al.*, 2000). Third, farmers confronted with drainage problems often apply mitigating strategies, such as finishing irrigation early in order to let water evaporate from the field, prolonged drainage and postponing the harvest date beyond the end of the growing cycle. Since these factors might affect the incidence of drainage problems considerably, the statistical model does not try to predict drainage problems as closely as possible. It is rather constituted as an explanatory model from which recommendations for improved water management can be deduced.

Factors at scheme level

(i) *Saturation of the drainage system.* The central management records the water levels in the Niono-Grüber drainage system monthly (Figure 6.1). The evolution in water level can be assumed analogous for the other drainage systems, since all of them are confronted with the same problems. When water levels are too high, the drainage system becomes saturated as it is no longer possible to evacuate water from the fields. The water level in the collector drain is highly variable throughout the growing season. It reaches its peak in September, and then drops steadily to its minimum level in January. The harvesting period coincides with this peak in September and the subsequent steady drop in the water level. While an exceptional unit might already be harvested in August, harvesting generally sets off in September and continues until the end of December. The harvest date within the year is thus used as a proxy for saturation of the drainage system. To facilitate the interpretation of results, the date is converted to a number starting from one for the date on which the first unit is harvested.

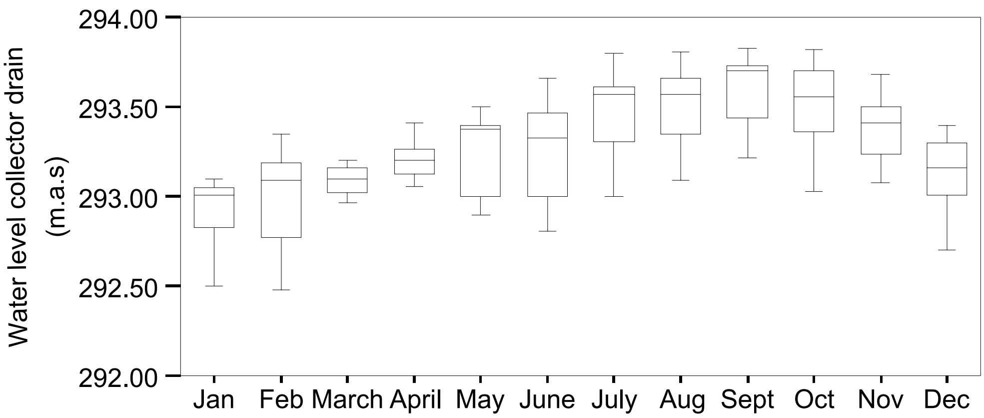


Figure 6.1 Average monthly water level of the Niono-Grüber collector drain throughout the year (period: 1997 to 2005)

(ii) *Maintenance level of the collector drain.* The collector drains in the Office du Niger irrigation scheme are in a notoriously bad shape. Only one of the bigger drains (the Niono-Grüber drain) has been rehabilitated between the growing seasons of 2004 and 2005. A dummy variable is used with a value of one for units pertaining to the Niono-Grüber drainage system after rehabilitation, and a value of zero otherwise.

Management practices at the tertiary level

(i) *Disparity in harvest date.* With water being permanently available, farmers determine their cropping calendar independently. Economic incentives and constraints resulted in a considerable disparity in planting and harvest dates within most tertiary blocks and even between neighboring fields. As field canals are used for irrigation as well as drainage, this disparity can have a direct impact on the incidence of drainage problems at harvest because of conflicts between irrigation and drainage and lateral seepage. Since for irrigation, the water level in the canals has to be superior to the field water level and vice versa for drainage, the two cannot occur simultaneously. Irrigation is generally considered more important than drainage and will thus get the priority (Bastiaens, 2004). In addition, depending on water management practices, field canals are often kept full if a water layer is present in some of its downstream fields. Consequently, drainage is not only impeded for the other fields, but lateral seepage from the canal might actually add water to them. Lateral seepage might also occur when adjacent rice basins still maintain a water layer. Usually, rice basins are drained about ten days before harvesting. A dummy variable is used that gets a value of one if none of the adjacent fields is harvested at least ten days later and a value of zero otherwise.

Disparity in harvest dates does not have to result automatically in drainage problems. Indeed, much depends on water management practices at plot level. First, reinforcing the contour dikes of the rice basins can control much of the lateral seepage. However, given the high prevalence of rats and other burrowing animals, this is a time-consuming task demanding quasi-permanent vigilance. Second, the depth of the water layer in the adjacent fields determines the rate of seepage and the risk of breaches in the contour dikes. Third, an improved use of the field canals can avoid much of the conflicts between irrigation and drainage. Good water management practices are however rarely implemented, since their benefits accrue mostly to the neighbors of those who apply them.

(ii) *Maintenance of the tertiary drain.* The unlined drainage canals are vulnerable to weed growth and deterioration of the canal bed and banks. Maintenance of the drainage canal involves cleaning the canal of weeds and if necessary, dredging its bed and reinforcing its banks. It usually takes place during the weeks before harvest, but is often neglected. Neglect of maintenance diminishes the capacity of the tertiary drains, forming a bottleneck for evacuation of drainage water to the secondary drains. In addition, farmers usually clean the part adjacent to their fields independently from each other, so that maintenance levels for the same drain can vary considerably in time and space. A variable is constructed for the maintenance level of the tertiary drain based on the average score of the different canal sections on the day of harvest of the unit. Scores range from 1 (good) to 3 (bad).

(iii) *Excess irrigation at tertiary block level.* Excess irrigation water at the tertiary block level has to be evacuated to the drainage system. With the drainage system constituting of communicating vessels, the impact of excess irrigation is dissipated over the entire drainage system. However, excess irrigation water has to be evacuated first through the tertiary drain, which can cause temporary congestion. Excess irrigation is assessed during the ten days before harvest of the unit and is calculated as:

$$\begin{array}{c} \text{Excess} \\ \text{irrigation} \\ \text{water} \end{array} = \begin{array}{c} \text{Water} \\ \text{supplied to the} \\ \text{tertiary block} \end{array} + \begin{array}{c} \text{Rainfall on} \\ \text{the cropped} \\ \text{surface} \end{array} - \begin{array}{c} \text{Evapotranspiration} \\ \text{in the tertiary block} \end{array} \qquad [\mathrm{m^3/ha}]$$

Since some of the excess water might be stored in the rice basins, or previously stored water might be drained during the ten days under consideration, the variable gives only an indicative value. For calculation procedures of the water requirement and water delivery, refer to Chapter 3. Almost all fields are harvested before the end of November. Afterwards, both water requirements and water supply to the tertiary blocks approach zero and excess irrigation water was put to zero.

(iv) *Concentration of harvest dates at tertiary block level.* While disparity in harvest date of adjacent fields can cause drainage problems, a concentration of harvest dates at tertiary block level results in a peak of drainage water, which might cause congestion in the tertiary drain. Therefore, the proportion of the tertiary block being drained during the ten days before harvest of the unit is another variable that needs to be considered.

The degree of saturation of the drainage system might have a considerable impact on the relation between some of the management practices and the incidence of drainage problems at harvest. In particular, excess irrigation water and concentration of harvest dates at tertiary block level are expected to be significant especially when evacuation of drainage water from the field is hampered by a congested collector drain, since they will aggravate existing problems. On the other hand, maintenance of the tertiary drain is expected to have an impact only when the collector drain is no longer saturated. Indeed, the tertiary drain can only evacuate the quantity the secondary drain and eventually collector drain are able to absorb. In order to take into account the level of saturation of the collector drain, the three variables for management practices at the tertiary level listed above are analyzed in interaction with the month in which harvesting took place. Since only a couple of units were harvested in August, this month is lumped together with September. Each variable is thus split into four variables, which have their specific value during one month, and a value of zero during the other months.

Characteristics of the measurement

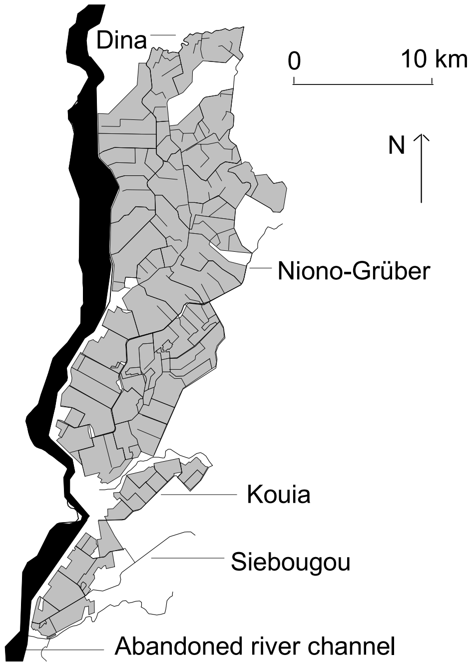
(i) *Size of the harvest unit.* Larger harvest units are expected to have a lower incidence of drainage problems. Indeed, size is positively correlated with consolidation of the harvest unit, so that edge effects, such as lateral seepage, are reduced. However, since the size of the harvest unit depends much on the shape and size of the rice plot, it is therefore not considered as a management practice that can be controlled by the farmer.

(ii) *Type of infrastructure.* In the rehabilitated part of the irrigation scheme, two types of infrastructure can be distinguished: the Arpon type and Retail type (Chapter 2). In the Arpon type, the tail end of the tertiary irrigation canal is linked directly to the tertiary drain of the adjacent block through an overflow structure. Excess irrigation water in the tertiary canal that does not discharge in field canals is transferred to the neighbors. This system does not give much incentive to avoid over-use. In the Retail type, the overflow structures in the tertiary irrigation canals are connected to the field canals. Nevertheless, it was shown that water use in tertiary blocks of the Arpon type is more efficient in comparison to the Retail type due to the smaller dimensions of the tertiary intake (Chapter 3).

(iii) *Year of the observation.* Since the degree of saturation of the collector drains can vary from one year to another, the year of the observation is also introduced as a variable.

Sample, data collection and statistical analysis

The harvest units pertain to a sample of 36 tertiary blocks from nine secondary canals and four drainage systems within the rehabilitated area (see Chapter 3). Data collection was repeated for the 2004 and 2005 growing season. Since harvest units in 2004 and 2005 usually do not coincide spatially, and the value of the independent variables can differ considerably between the two years, they are considered independent measurements. Measurements from the same tertiary block are however not independent, since factors not included in the model, such as topographic level of the block, might affect the incidence of drainage problems in all of its harvest units. The tertiary blocks being a random sample within the population, the coefficients of the tertiary block effect are assumed normally distributed around a population mean (Diez Roux, 2002). The sample structure is presented in Table 6.2.



Map 6.1 Detailed map of the Niono and N'Debougou zones with indication of the drainage systems

The harvest units from the sample were monitored weekly, during which the drainage condition was observed and the harvest date obtained from farmers present at the field or estimated. The size of harvest units was calculated using the land registry of the Office du Niger. The maintenance level of the tertiary drain was monitored fortnightly throughout the growing season.

The dependent variable being a binary variable indicating whether yes or no a harvest unit was confronted with drainage problems, a binary logistic regression model is used (Thomas, 1997):

$$\ln\left(\frac{P}{1-P}\right) = \beta_1 + \beta_2 X_2 + ... + \beta_k X_k + TBE + \varepsilon$$

where P the probability of encountering drainage problems (1 = yes; 0 = no), P/(1-P) is the odds ratio and its natural logarithm the logit. X_2 to X_n are the variables described in section 2.2, β_1 to β_n the model coefficients and ε the error term. A multilevel model was fitted using SAS GLIMMIX. The tertiary block effect (TBE) was controlled for by using a random intercept model with varying intercepts for each of the tertiary blocks from the sample (Diez Roux, 2002). For the dummy variables, the model coefficients are calculated by comparing each of the categories to a reference category. Model coefficients are translated in the change in probability for a unit increase in the independent variables. In the case of the continuous variables, the change in probability can be calculated for any range of change, assuming the logit is linear in the variables (Hosmer and Lemeshow, 1989).

Table 6.2 Sample structure

Drainage system	Number of tertiary blocks in the sample	Number of harvest units in the sample		
		2004	2005	Total
Niono-Grüber	20	338	447	785
Siebougou	4	101	135	236
Kouia	4	67	92	159
Dina	8	117	190	307
Total	36	623	864	1487

6.3 Results and discussion

37 % of harvest units and 34 % of the total surface of tertiary blocks from the sample were confronted with drainage problems at harvest. Among the variables of the characteristics of the measurements, only the size of the harvest unit is significant (Table 6.3). Both the variables at scheme level, i.e. harvest date (the proxy for saturation of the collector drain) and maintenance of the collector drain, are highly significant ($p < 0.001$). Starting from the second decade of November, when the water level in the collector drain is about halfway between its maximum and minimum, the average probability of drainage problems is only 18 % (Figure 6.2). Furthermore, a delay of 20 days in the cropping calendar corresponds to a decrease in probability of drainage problems of 15 % (Figure 6.3). About the same decrease is attained when the collector drain is properly maintained (Table 6.3). Most farmers currently blame the central management for their drainage problems because of the poor condition of secondary and collector drains (Keita, 2003). While this is indeed an important factor, the saturation of the drainage system due to the over-supply of irrigation water is of equal or even more importance. Given that the filling-up of the natural depressions, which are the only drainage outlet for the irrigation scheme, poses an ultimate bottleneck, limiting the quantity of drainage water would be the single most effective solution to the drainage problem. This can be achieved by improving irrigation efficiency. Here, the central management and farmers share responsibility, as both are involved in the operation of the irrigation network and apply minimal water management strategies in doing so (Chapter 3).

Table 6.3 Results of the multilevel logistic regression model predicting the probability of drainage problems at harvest

Variable	Sig.	Odds ratio	% change in probability
Harvest date	0.000***	0.964	-1
Maintenance of the collector drain (if not maintained)	0.011*	1.757	14
Disparity in harvest date with neighboring fields (if no disparity)	0.003**	0.651	-9
Maintenance level tertiary drain in interaction with month - September	0.551	0.794	-5
October	0.294	0.758	-6
November	0.747	1.085	2
December	0.014*	2.580	23
Excess irrigation during the decade before harvesting in interaction with month - September	0.100	0.999	0
October	0.134	1.000	0
November	0.394	1.000	0
December	0.936	1.000	0
Proportion of the tertiary block surface being drained in the same 10 days in interaction with month - September	0.141	0.946	-1
October	0.317	1.007	0
November	0.751	0.999	0
December	0.717	0.985	0
Size of the harvest unit	0.008**	0.772	-6
Type of infrastructure (if Retail)	0.159	1.417	8
Year (if 2004)	0.097	1.322	7
Constant	0.000***	31.406	

* Significant at the 5 % level
** Significant at the 1 % level
*** Significant at the 0.1 % level

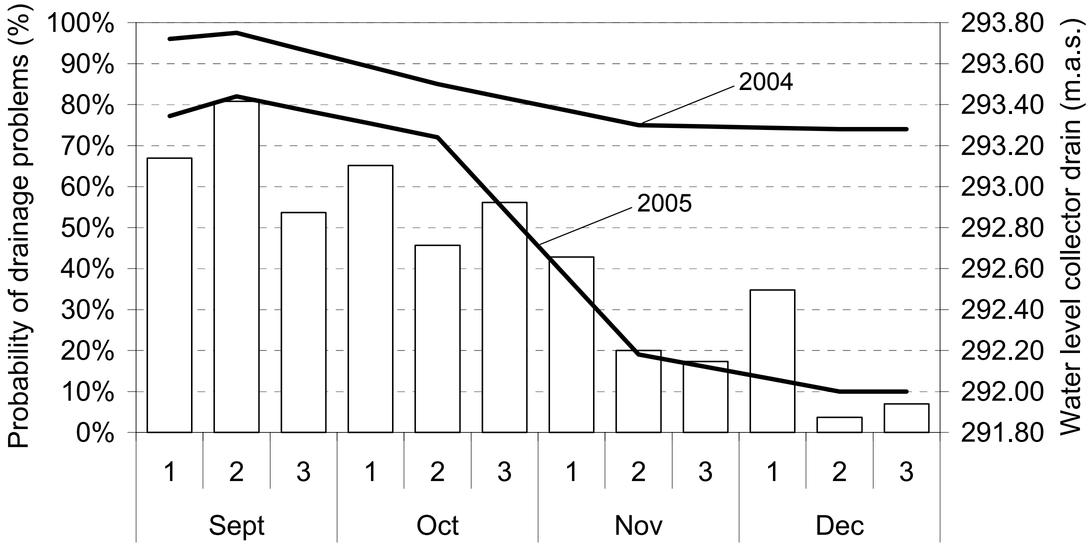


Figure 6.2 Variation of the probability that drainage problems occur at harvest (bars) and the water level in the Niono-Grüber collector drain for each 10-day period in 2004 and 2005 (lines)

These strategies originate from the abundant availability of water, which makes inefficient irrigation possible without risking water shortages. Consequently, farmers and managers have to be convinced of the relation between the practice of over-supply of water for irrigation and drainage problems at harvest. Efforts of individual farmers to reduce over-supply are dissipated through the entire drainage system, which reduces the incentives to provide these efforts. The issue should thus be tackled at the collective level. Water Users Associations and the so-called Joint Committees that unite farmers and Office du Niger staff could provide the necessary platform. In the Office du Niger, Water Users Associations are being set up at tertiary block level, for which at a later stage, umbrella organizations will be created at secondary and primary level. Joint Committees already exist for decision-making on maintenance and land allocation, but not yet for water management. The irrigation scheme's historical path has however lead farmers to consider the water resource as an open access regime, where fellow farmers cannot be held accountable for problems they incur on others (Chapter 7). Consequently, cooperation among farmers to achieve a common goal is socially difficult to establish (Chapter 4). Tackling the issue of over-supply will thus require a mentality shift.

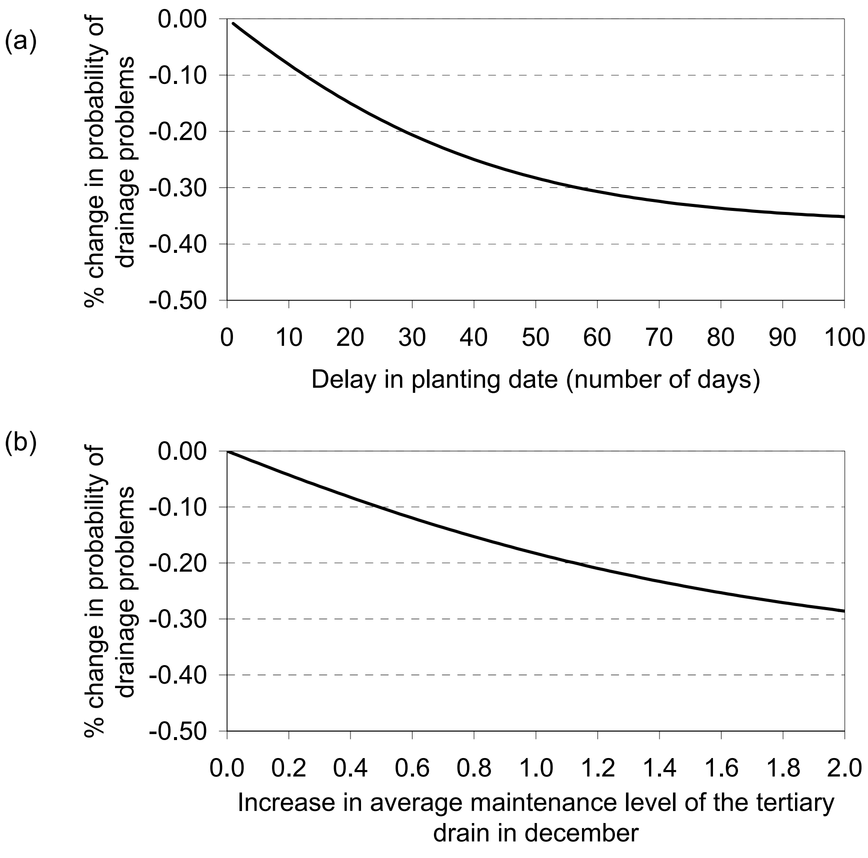


Figure 6.3 Change in probability that drainage problems occur for (a) various delays in cropping calendar and (b) increase in average maintenance level in December

Among the variables for the management practices at the tertiary level, the disparity in harvest dates with adjacent fields and the maintenance level of the tertiary drain are significant. Maintenance has a significant impact in December only, when the collector drain attains its minimum level, but only a few fields are harvested. A reduction in the average score for maintenance of one, decreases the probability of drainage problems with more than 20 % (Figure 6.3). The effect in the other months is much smaller and furthermore not significant. Maintenance of the tertiary drain is now the primary focus of sensitization sessions and capacity building aiming at improving water management practices at the tertiary level. As long as the collector drain remains saturated, this measure does however not make much sense.

Avoiding a disparity in harvest dates of more than ten days with adjacent fields has a considerable impact throughout the period of harvesting (Table 6.3). Coordination of the cropping calendar is however difficult to establish. Many aspects are involved in choosing a cropping calendar and most farmers think it should be an individual decision (Keita, 2003). Disparities even exist between harvest units belonging to the same farmer. Given the large impact on the incidence of drainage problems at harvest on the one hand, and the difficulty in coordinating harvest dates on the other hand, water management practices at plot level should be the focus of attention. Again, since the farmers that provide most of the effort are not the ones who will benefit from them, it should be a matter of tertiary level Water Users Associations.

Even though not significant, the results for the proportion of the tertiary block being drained during the same ten days as the harvest unit and excess irrigation during the decade before harvesting are counterintuitive. Indeed, the average proportion is larger for harvest units without than for those with drainage problems. This might be because a large proportion of the tertiary block being harvested in the same period implies less irrigation and thus creates favorable circumstances for mitigating strategies such as allowing water to evaporate from the field in stead of draining. Regarding excess irrigation at tertiary block level, the value is also higher for units without than with drainage problems. A possible explanation is that tertiary blocks in depressions that are regularly confronted with drainage problems might suspend irrigation altogether in an early stage. This might explain the negative values for excess irrigation. The degree of excess irrigation might thus be a consequence of drainage problems rather than a cause.

Box 7 Drainage problems and rice quality

Many farmers in the Office du Niger irrigation scheme relate drainage problems with a deterioration of rice quality (Keita, 2003). In order to asses this relation, paddy samples were collected in fields with and without drainage problems. In total, 51 samples of at least 3 kg were collected in 2004 and 2005, preferably the day of threshing. The period in between harvesting and threshing, in which the harvested rice might have been put into sheaves to dry, was not controlled for. Seed moisture was measured with a humidimeter immediately after the collection of the sample (taking an average of 3 measurements) and then, the samples were spread out to dry in the shade. Subsequently, the samples were cleaned and milled using the same village mill for all of them. The rice samples were then classified according to their quality, taking into account their variety. Class 1 contained rice of very good quality, meaning the grains were white and long. Class 2 resembled class 1, but contained more broken grains. Rice of class 3 was less white and had mostly broken grains, but its quality was still acceptable. Rice of class 4 and 5 would be difficult to market, with respectively opaque and discolored grains being mostly broken. Only 14 samples were classified in class 4 or 5, and as their low quality probably resulted from a particular incident, they were excluded from further analysis. Results are presented in Figure 6.4 and Table 6.4.

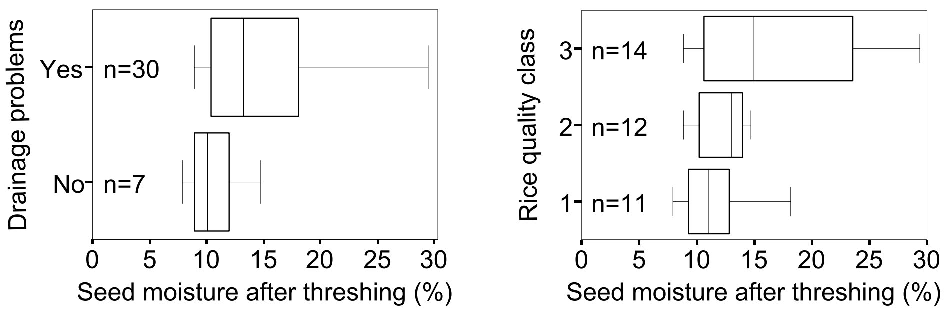


Figure 6.4 Boxplots of seed moisture after threshing in function of drainage problems at harvest (left) and rice quality class (right)

Table 6.4 Association of drainage problems at harvest with rice quality

Drainage problem at harvest	Rice quality class			
	1	2	3	Total
No	71%	29%	0%	100%
Yes	20%	33%	47%	100%
Total	30%	32%	38%	100%

Given the small sample size, results should be interpreted with care. It seems however that good drainage conditions can indeed avoid quality loss related to excessive moisture. Harvesting under wet conditions increases the probability that the rice is still humid. Furthermore, quality loss appears unavoidable for very humid paddy samples (humidity above 20 %). Drying harvested rice before threshing might save rice quality but offers no guarantee. Drying conditions might still influence final quality considerably, but were not monitored during this survey.

6.4 Conclusion

Inadequate drainage in irrigation schemes is a growing concern because of consequences on agricultural production and on the environment. While most of the research on water management focuses on irrigation, this chapter discusses the topic from the angle of drainage. Since a large part of the solution consists in water management practices at the collective level, their impact on drainage problems is quantified so that recommendations can be formulated.

Drainage problems at the time of harvest are widespread in the Office du Niger irrigation scheme, and incur increased production costs as well as production and/or quality loss. The rice schemes discharge water into natural depressions and their filling-up poses an ultimate bottleneck to the disposal of drainage water. For the 2004 and 2005 main growing seasons, on about one third of the surface area, it was impossible to evacuate water from the field for harvesting. Statistical analysis of the incidence of drainage problems at field level confirms that the principal causes of drainage problems in the Office du Niger irrigation scheme are the saturation of the drainage system with excess irrigation water and insufficient maintenance of the collector drains. Once the collector drain is no longer saturated, maintenance of the tertiary drain becomes important, while the disparity in harvest dates of neighboring fields always contributes to the drainage problem. Except for maintenance of the collector drain, which is the responsibility of the Office du Niger, the solution largely consists in improving farmers' water management practices. The latter depends on two preconditions. First, farmers have to be convinced that drainage problems at harvest are caused not just by the diminished capacity of the collector drain, but partly by their own doing when they over-use irrigation water. Second, since the benefits of an individual's efforts often accrue to neighbors or are dissipated through the entire drainage system, water management practices related to drainage should be tackled at the collective level. The Water Users Associations currently being set up in the irrigation scheme could provide the necessary platform.

PART II

ANALYSIS OF THE SOCIAL FORCES BEHIND FARMERS' WATER MANAGEMENT

Summary

Social relations between water users, their attitude toward the water resources and irrigation infrastructure, and the legitimacy of formal and informal leaders are all social forces that shape the daily practice of water management. Any intervention is subject to them and considering them would greatly increase their effectiveness. Part II of this dissertation investigates these social forces behind water management. Without aiming to be exhaustive, it scrutinizes two issues of particular importance. First, Water Users Associations (WUAs) could provide a much-needed platform to institutionalize collective action. Despite considerable efforts to introduce them, informal patterns of decision-making on water management remain dominant. To be more effective, WUAs should therefore adopt some crucial features of informal decision-making, including light and flexible procedures and the involvement of village leadership. Indeed, in the Office du Niger irrigation scheme, as in many other African publicly funded irrigation schemes, new authorities are hard to establish. Involving existing sources of authority, usually present at village level, has been observed to strongly favor the performance of WUAs. Second, recent socio-economic evolutions might thwart efforts to promote collective action through sensitization and training of farmers. Indeed, the economic success of the reforms have created many employment opportunities outside rice farming, and there exists a clear trend of farmers diversifying their sources of income. This trend results in the increasing employment of wage laborers who are assigned the task of water management. It appeared that wage laborers are less motivated for collective action. As they are furthermore excluded from existing patterns of information transfer, the training and sensitization sessions should explicitly consider them as a target group.

Chapter 7
Formal and informal decision-making on water management at village level

Abstract[1]

Water Users Associations (WUAs) are all too often considered a panacea for improving water management in irrigation schemes. Where grassroots movements are absent, they are usually imposed on farmers by national governments, NGOs and international donors, without fully considering existing forms of organization. This also happened in the Office du Niger irrigation scheme, where after a partial Irrigation Management Transfer WUAs were created to fill the resulting power vacuum. This chapter demonstrates that, despite active efforts to organize farmers in WUAs, informal patterns of decision-making remain dominant. Given the shortcomings of these informal patterns, WUAs could provide a much-needed platform for institutionalizing collective action, on the condition that farmers accept them. Therefore, WUAs should adopt some crucial characteristics of informal patterns of decision-making, while avoiding their weaknesses. First, making use of the existing authority of village leadership and the central management can improve the credibility of WUAs. Second, allowing flexibility in procedures and rules can make them more appropriate for dealing with collective action problems that are typically temporary and specific. On the other hand, formalizing the current pattern of conflict management and sanctioning might enhance its sphere of action and tackle the current absence of firm engagement with respect to some informal management decisions. In addition, WUAs should represent and be accountable to all farmers, including those residing outside the village community.

[1] This chapter is adapted from: Vandersypen, K., Keita, A. C. T., Coulibaly, Y., Raes, D., and Jamin, J.-Y. (In Press). Formal and informal decision-making on water management at village level. A case study in the Office du Niger irrigation scheme in Mali. Water Resources Research.

7.1 Introduction

In the context of Irrigation Management Transfer (IMT), Water Users Associations (WUAs) are being promoted as the center of decision-making on water management. The configuration of water management can take a wide variety of forms, which can be broadly divided in two categories. In the first category, WUAs are responsible for water management of the whole irrigation scheme. Nevertheless, they can delegate operation and maintenance of the main system to professional staff. In the second category, a central agency (private or government) is responsible for main-system operation and maintenance, whereas WUAs are responsible for water management at sub-systems, typically tertiary level (Groenfeldt and Svendsen, 2000; Hearne, 2004). WUAs do not arise spontaneously in most cases, but are imposed on farmers in a top down way by national governments, NGOs and international donors (Jamin *et al.*, 2005). Early experiences, which mostly took place in Asia, learnt that farmers should set the rules and regulations of WUAs. Moreover, WUAs should involve local decision-makers in their set-up and build upon existing organizational capacity (Meinzen-Dick and Reidinger, 1995; Maganga *et al.*, 2004). Implementing agencies however frequently neglect these recommendations and the result is that many WUAs remain merely legal constructs (Sokile and van Koppen, 2004). Existing forms of organization are strongest in indigenous irrigation schemes, where water management is shaped by customary law and embedded in the social and economical structure of society (Diemer, 1990; Watson *et al.*, 1998). One of their prominent features is the strong involvement of village leadership in water management. Even in larger indigenous irrigation schemes, leaders of sub-units ultimately give account to the village leadership (Adams *et al.* 1994; Norman, 1997). In government-run irrigation schemes, decades of farmers' dependency on the central agency have crippled their organizational capacity (Shah *et al.*, 2002). Nevertheless, some informal patterns of decision-making on water management at farmers' level might have emerged.

The Office du Niger irrigation scheme is a classic example of the above-described evolution. Some years after IMT, WUAs were created to fill the power vacuum left by the IMT. This chapter demonstrates that despite active efforts to formally organize farmers in WUAs, informal patterns of water management remain dominant. Given the flaws of these informal patterns, this represents a missed opportunity. This argument is built through an institutional analysis of both formal and informal centers of decision-making on water management. Institutions in this chapter are understood as 'humanly devised constraints that shape human interaction' (North, 1990). The difference between formal and informal institutions is not clear-cut. ‘Formal’ is defined as following fixed procedures (mostly written down in statutes) and molded in an organization backed by the legal system (in this context a WUA), while ‘informal’ means following customary norms and habits and based on conventions (Onibon *et al.*, 1999). In principle, both formal and informal institutions can effectively solve collective action problems, even though establishing formal organizations might give the necessary impetus in groups already willing to cooperate (Meinzen-Dick *et al.*, 2002). Moreover, formal institutions are generally complemented with informal ones. As such, the same formal institutions applied by groups with different informal ones, might produce different outcomes (North, 1990).

The analytical framework used in this chapter draws in part from the framework proposed by Ostrom (1990; 1993). In summary, it states that users do or do not support institutional change, depending on the trade-off of expected costs and benefits. These in turn depend on social norms, users’ internal discount rate and situational variables, such as characteristics of the user group and resource and the socio-economic environment. From that, design principles can be deduced for successful institutions. While these design principles might be a necessary condition for institutions to work, they are certainly not a sufficient condition. Institutions must therefore be understood in their historical and socio-cultural context (Cleaver, 1999; Steins and Edwards, 1999). In particular, this context has shaped social relations among users, their attitude toward the resource and the legitimacy of formal and informal leaders. Understanding informal institutions can contribute to designing better ways for implementing institutional change, for example by including representation of informal and accountable leaders (Ribot, 1996; Wester *et al.*, 2003).

7.2 Fieldwork methodology and data analysis

Fieldwork on farmers’ water management and performance was conducted in 2004 and 2005 in 9 villages from the Niono and N’Debougou zones (see Map 2.2). Data for this study result essentially from qualitative research methods. At village level, two series of focused interviews (Flick, 1998) with village leaders took place (see Appendix 3). In the first series, the village history and social composition were discussed. A second series assessed the functioning of WUAs and informal patterns of water management at the village level. Table 7.1 presents key statistics on the sample villages. Next, a sample of 36 tertiary blocks was constructed for an in-depth study, by picking out four tertiary blocks within each village (see

Chapter 3). Group interviews for each of the tertiary blocks were conducted, in which decision-making, communication and coordination on water management were addressed using a structured, open question interview guide. Information obtained through the interviews was then complemented by frequent observations of water management activities on the field and informal discussions with farmers of the studied tertiary blocks (22 in total) on their principles of conduct regarding water management.

Table 7.1 Key statistics on the sample villages

Village	Population	Number of tertiary canals	Location in the irrigation scheme	Zone
Médina-Coura	2821	34	Top end position	N'Debougou
Tiemedely-Coura	2811	34	Middle position	N'Debougou
Kanassako	2471	29	Middle position	N'Debougou
Médina	3473	40	Middle position	Niono
Moussa-Wèrè	1123	18	Tail end position	Niono
Peguena	1005	10	Top end position	Niono
Coloni	3150	33	Top end position	Niono
Suigui-Vocè	1403	25	Tail end position	N'Debougou
Fassun	2189	17	Tail end position	N'Debougou

Table 7.2 Key characteristics of the sample of tertiary canals

	Surface (ha)	Number of farmers	Proportion of non-residents (%)	Number of leaseholders
Mean	18.4	7.9	14	1
Minimum	6.6	2	0	0
Maximum	48.3	19	56	6

Table 7.2 gives key characteristics of the sample of tertiary canals. A frequent presence in the villages, together with the researchers' attachment to a popular local research center that provided highly valued technical assistance, allowed the development of a relationship of trust. Such a relationship is essential for obtaining information on taboo issues such as conflicts and illegal practices. Village interviews were made enjoyable for all participants by offering tea, which created a relaxed atmosphere and allowed to extend considerably the interview without loss of concentration of both interviewers and respondents. Content analysis was used to analyze empirical data (Miles and Huberman, 1994). In order to further scrutinize empirical data, triangulation methods were used (Baxter and Eyles, 1997). First, data were discussed in expert interviews with key-informants in the study area, such as local researchers, Office du Niger officials and leaders from the farmers' syndicate. Next, the researchers participated in various project evaluation meetings and information sessions on WUAs organized by the central management. A last source of information consisted in official and informal reports on water management and WUAs developed by researchers and

national and international experts solicited to design, implement and evaluate WUAs in the irrigation scheme.

7.3 Centers of decision-making in the Office du Niger

Before reforms, the central management had a monopoly on virtually every sphere of decision-making, thereby erasing most traditional forms of organization (Magasa, 1978; Schreyger, 1984). One of the very few surviving customary institutions is the village chieftainship. The moment of their creation, the villages in the Office du Niger irrigation schemes established a village chief, usually was the male family head of one of the first settled families. Since before reforms, the traditional duties of the village chief, such as management of the village territory, housing and administration, were in the hands of the central management, their sphere of action was severely reduced. Nevertheless, they managed to take the lead role in conflict management at the village level through informal jurisdiction and are generally recognized and respected by the villagers. Table 7.3 shows the dates of creation of the sample villages and describes the origin of the population. Downsizing the central management led to its responsibility being reduced to water and land management. The other competences were transferred to existing and newly created centers of decision-making. The judiciary responsibilities were transferred to the Malian national level, and the registry office, public security, education and health were handed over to the prefectures and communes. Communes are the lowest formal level of government and are generally compiled of several villages (Hellevik, 2004). The role of the village chief is now administratively formalized. Indeed, even though villages are not a separate administrative level, they are an important entity for consultancy and conflict resolution within the commune (Hellevik, 2004).

With the liberalization of crop production and marketing, village cooperatives have been created in the 1980s to manage agricultural input supply and processing and marketing of production, which before were also in the hands of the central management. The cooperatives were meant to be economically profitable, with earnings invested in social infrastructure such as schools and health centers. Consequently, successful cooperatives were able to play an important role in decision-making at the village level. Generally, the village chief or one of his counselors took a lead role in the cooperative as its president or secretary, so that strong ties between the two have developed (Traoré and Spinat, 2002).

Table 7.3 Origin of the population and functioning of the village cooperative for the sample villages

Village	Date of creation	Origin of the population	Functioning of village cooperatives
Médina-Coura	1955	Dominant group (Minianka) originating from the same region and installed by force, complemented by a group of mixed ethnicity	In difficulty, involved in a village dispute
Tiemedely-Coura	1965	Mixed population originating from different regions in Mali and installed both voluntarily and by force	Functional, good relation with competing cooperative
Kanassako	(*)	Dominant group of original inhabitants, complement by relative recent newcomers	Successful
Médina	1940	Mixed population originating from different regions in Mali and installed voluntarily	In difficulty, involved in a dispute with the village chief
Moussa-Wèrè	1959	Mixed population of inhabitants of existing nearby villages and immigrants from other regions in Mali, installed both voluntarily and by force	Bankrupt, competing cooperative also bankrupt
Peguena	1937	Dominant group of mixed ethnicity but originating from the same region, complemented by a group originating from different regions, relatively few recent newcomers	In difficulty, good relation with competing cooperatives
Coloni	1937	Mixed population of inhabitants of existing nearby villages and immigrants from other regions in Mali, installed both voluntarily and by force	In difficulty, bad relation with competing cooperatives
Suigui-Vocè	1940	Nearly homogeneous population originating from the same village in Burkina Faso, relatively few recent newcomers	Bankrupt, replaced by functional cooperative
Fassun	1962	Dominant group (Bambara) originating from the same region and installed voluntarily, complemented by a group of mixed ethnicity	Functional, good relation with competing cooperative

(*) The village existed before the irrigation scheme was constructed

Box 8 The realm of the Office du Niger

The Office du Niger has often been described as a state within the state, and even though much has changed since the reforms, the area still carries many tokens of the profound impact of the irrigation scheme on everyday life. When you cross the Markala dam over the Niger River, the many billboards showing maps of the canal network make quite clear that you enter the Office du Niger's realm. The dam could be considered as the entrance gate. In the early days, farmers who violated the central management's rules were literally thrown out. The farmer and his family, with their few sticks of furniture, were put on a chariot and dumped on the other side of the Markala dam (Magasa, 1978). Inside the scheme, one of the first villages you will meet is actually called "Point A", after the gigantic sluice gates at the head of the three main hydraulic axes. Even though each village has a proper name, many are nicknamed after the nearby secondary canal or the kilometer point used by topographers. For example, no one knows the actual name of "N10", and asking the direction to "le kilomètre 36" makes perfectly sense. A few farmers actually add the cadastral number of their plot to their name so you will know exactly who they are. Roads to travel in the area simply follow canals, which are the center of peoples' lives. Concrete stairs made in their banks are filled all day long with woman and girls doing laundry or the dishes. Children play in them with self-made rafts and boats. At dusk, men go there to take a bath and clean their motorbikes and cars. Occasionally, an exposed thief is thrown in a canal with hands and feet cuffed. Young and old go fishing and the area supports a few hamlets of Bozo fishermen that were attracted by the irrigation scheme's many canals. Small boys bring goats and cows to drink and during the dry season, hundreds of thousands of heads of cattle pass through the irrigation scheme on their way from north to south to sip a drink. Living in the Office du Niger irrigation scheme once meant destitution and oppression, but now it can be a reason of pride and a source of wealth. Much of the cattle herded through the irrigation scheme by Peulh herdsman actually belong to residents of the Office du Niger. When people visit relatives, they take a few bags of rice with them as telling presents. Chiefs in the hierarchy of the central management are still very much considered chiefs, although they lost much of their power. They are still treated with consideration and are bound to do the opening speech at traditional dance evenings and to cut the tape of the new school.

The success of the village cooperatives is variable. Already in the 1990s, the majority of cooperatives faced financial problems, often caused by mismanagement and corruption (Traoré and Spinat, 2002). Moreover, the cooperative leaders are often accused of favoritism, which prejudiced their legitimacy in the view of villagers (Yung and Tailly-Sada, 1992). In response, groups of farmers created independent cooperatives. Ensuing competition often led to tensions at the village level and the development of opposing factions, although in the course of years, the opposing groups came to terms in most of the villages. On the other side, successful cooperatives often strengthened the social cohesion of the village. Table 7.3 gives an overview of the functioning of the village cooperatives for the sample villages. According to a study by PCPS (2002) that analyzed the functioning of village cooperatives, this figure is quite representative for the irrigation scheme.

Even though water management is still the competence of the central management, a partial transfer to farmers has taken place. This transfer has been more complete towards the lower levels of the hierarchic canal network. The central management of the Office du Niger bears the sole responsibility for water management at the primary canal level. At the secondary level, farmers participate in decision-making in Joint Committees. At the tertiary level, water management is entirely left to farmers (Touré *et al.*, 1997). Certain regulations, elaborated in a three-yearly contract negotiated between the Malian state, the central management and farmers' representatives, limit farmers' liberty of action (Couture *et al.*, 2002). The regulations prescribe the maintenance of the tertiary infrastructure, the cropping calendar and cultural practices to intensify rice production. They further stipulate farmers' obligation to limit water use and practice double cropping on designated plots. There were however no structures to monitor compliance with these regulations, so that a certain anarchy and inability to solve collective action problems quickly became apparent. As a response, WUAs were created by donor-funded projects, designed to form the center of decision-making on water management at the tertiary level.

7.4 Decision-making on water management

7.4.1 Water Users Associations at the village level

In 1996, a first project established WUAs at the village level, the so-called 'Comités Paritaires de Partiteur' (CPP). Institutionally inserted in the village cooperative, they are actually not composed of farmers, but of tertiary canal chiefs. At every tertiary block, one of the farmers is elected as chief and acts as the representative for the tertiary block, while implementing decisions taken by the CPP. The CPP contains two or more canal chiefs, elected by the general assembly of the village cooperative, in addition to the water guard and an official of the Office du Niger. One of the tertiary canal chiefs is appointed as head of the CPP. The duties assigned to the CPP are to assure water delivery to the tertiary blocks through a hierarchical system of communication between farmers, canal chiefs, the head of the CPP and the water guard. Further, it should plan and monitor tertiary infrastructure maintenance (Sogreah/Bceom/Betico, 1999; CEFE Consultants, 2000; CDP, 2004). Next, the CPP backs up the canal chiefs in implementing and monitoring its decisions and regulations on water management. The basis of authority for canal chiefs and the CPP is their power to sanction rule-breaking farmers by proposing their eviction from their plot to the Joint Committee on Land Management (Sogreah/Bceom/Betico, 1999). Lastly, the CPP should provide a platform for conflict settlement on water management issues and should be the official point of contact at the village level for the central management.

To date, the CPPs have been seldom effectively established (CDP, 2004). In most of the villages throughout the irrigation scheme, the posts of canal chief and head of the CPP are filled, but meetings do not take place and none of the CPPs assigned functions is carried out. As to the canal chiefs, group discussions revealed that all but one of the tertiary blocks from the sample have one, even though not all farmers are aware of it. This finding is confirmed by a survey of 127 farmers in 11 villages by Bastiaens (2005), where 32 % of the interviewed farmers reported that they have no canal chief. Since a complete list of the canal chiefs exists at the central management of the irrigation scheme, it can be assumed that the respondents are not aware of the presence of a canal chief. Another 10 % of respondents stated that their canal chief does not take on any of his assigned functions. Furthermore, decisions by the canal chief are often not respected, which makes his function largely meaningless.

The prime reason for the lack of adoption of the CPP is the absence of direct benefits it offers. Indeed, the ample and flexible water supply allows farmers and the water guard to circumvent the need for communication by keeping the secondary canal continuously at full capacity (Chapter 3). Regarding planning and monitoring tertiary infrastructure maintenance, the procedures, including obligatory meetings of which written records should be kept, are considered too heavy. The proportional equivalence between benefits and costs, one of the design principles for successful institutions, is thus violated (Ostrom, 1993). Furthermore, patterns of conflict management and information transfer already existed. Embedded in the social structure of the village, they have a natural authority that the artificially created CPPs lack (see further details below). Indeed, where strong informal institutions de facto exercise certain powers, new formal institutions are often unable to take these over and remain ineffective (Onibon *et al.*, 1999). The second reason is the inherent flaw that a WUA operating at the village level is not fit to deal with specific water management issues that might arise on a particular tertiary block. This lack of fit between the boundaries of the resource and the community to whom powers have been transferred has often thwarted institutional change (Cleaver, 1999).

Nevertheless, some individual CPP heads have assumed a role in water management, if not the intended role. In four out of the nine sample villages, they pass on information between farmers and the water guard and are the mouthpiece of farmers vis-à-vis the central management. Apart from that, they are often called upon to substitute for the water guard when the latter is absent, a task that is not among their official competences. These CPP heads' authority is based on their good relationship with the village chief and/or president of the cooperative, who in fact delegate water management tasks to them and lend them their authority. For example, as it has been observed in the Peguena village, the head of the CPP can be one of the advisers of the village chief, and is thus part of the chieftaincy. As such, the village leadership plays a vital role in the performance of these individual CPP heads. The importance of village leadership for collective action in this region has been pointed out by Vedeld (2000). The functioning of the village cooperative might be another decisive factor. In four out of five sample villages with the CPP head playing no role at all, the village cooperative is in difficulty or went bankrupt (Table 7.4). This observation reveals an institutional flaw. The village cooperative being the anchor for the CPP, it is not clear what should happen when the cooperative no longer exists. On the other hand, the CPP has never functioned in these villages, regardless of what happened with the village cooperative. Rather than a causal relation between the two, probably a third factor, such as the strength of village leadership, is responsible for both.

Canal chiefs, who operate at tertiary block level, have little substance as well. Several issues are unfavorable to the authority of the canal chiefs. First, the election process of the canal chiefs was often flawed. The survey by Bastiaens (2005) showed that in only 53 % of the cases, the farmers of the tertiary block elected the canal chief freely, while in 37 % of the cases, Office du Niger agents appointed the chief either directly, or indirectly by putting forward stringent selection criteria. Second, the sanctioning system that should back up the canal chief is absent, given that the CPP are not functional, violating another of the design principles for successful institutions (Ostrom, 1993). A last and more fundamental reason, as revealed by the informal interviews with farmers and village chiefs, is the fact that most farmers find it difficult to accept the authority of a fellow farmer. Indeed, the very idea of electing a canal chief between their peers was imposed on them. The role of culture -in this case posing a constraint on institutional development- has often been underestimated while promoting management transfer (Cleaver, 1999). Nevertheless, some individual canal chiefs still managed to establish a personal authority concerning water management. This authority is largely based on their conviction of its importance and facilitated by their strong personality and frequent physical presence on the tertiary block. In the villages of the case studies, on average one quarter of canal chiefs are reported to possess such qualities.

Table 7.4 Association of the actual role of the head of the CPP with the functioning of the village cooperative

Functioning of the village cooperative	Actual role of the CPP			
	The head of the CPP exercises (part of) his assigned role		The head of the CPP plays no role at all	
Functional or successful	2	Tiemedely-Coura, Kanasakko	1	Fassun
In difficulty or-bankrupt	2	Médina-Coura, Peguena	4	Medina, Moussa-Wèrè, Coloni, Suigui-Vocè
Total	4		5	

7.4.2 Water Users Associations at the tertiary level

Since 2002, in view of the lack of adoption of CPPs, new WUAs with competences on tertiary level water management are being set up at the level of each tertiary block. The ultimate objectives are ambitious. First, they want to support collective action for water management by offering a formal structure. The WUA will put forward an internal code that institutionalizes water management rules. The code can provide sanctions for rule breaking that are legally enforceable (BRL Ingénierie, 2004). Second, the tertiary level WUA will form the basis for bottom-up representation in federations that will take on water management responsibilities currently assigned to the central management of the irrigation scheme. The ultimate goal is to arrive at an exclusively farmer-managed irrigation scheme (CDP, 2004). However, in a first step, the competences of these WUAs, called 'Organisations d'Entretien du Réseau Tertiaire' (OERT), are restricted to maintenance. They do not replace existing village level CPPs, as the latter have much more complete competences on water management. The articulation between the two remains unclear though. For the time being, both will coexist without being linked to one another. So far, none are very active, and there is no competition between them. In addition, most of the time, the canal chief is also president of the OERT. It can be expected that when umbrella organizations for OERTs are created, the heads of the CPPs will be incorporated in a similar manner.

The set-up of OERTs, intended to promote farmers' participation, paradoxically excludes their involvement. The internal code, designed by the implementing agency (a local NGO), is identical for all of them. It states that membership of an OERT is determined through ownership of a plot on the tertiary block and is mandatory. Like the CPPs, OERTs have a rather heavy formal structure. They are chaired by a president and have two divisions for a total of six active members, among which are a treasurer and a secretary. The code provides for at least two meetings a year on maintenance programming, of which written records are to be kept. It stipulates furthermore that members should make financial contributions, which are administered in a deposit and used for maintenance works.

The success of OERTs cannot yet be fully assessed. From the experience of the first OERTs, some early conclusions can however be drawn. First, most farmers are convinced that OERTs are useful and find they facilitate collective action for maintenance (Etz, 2005; Bastiaens, 2005). However, only a handful of OERTs created are actually functional, and even then, most of the formal aspects of the organization are systematically disregarded. The position of the president and active members is mostly filled in, but official meetings do not take place, no written records are kept (80 % of farmers in the area are illiterate), and very few OERTs collected financial contributions (CDP, 2004; Etz, 2005). Its principal merit lies in the fact that a formal platform for collective action is created, which is recognized by all farmers of the tertiary block. Three reasons for its relative success can be identified. First, information and sensitization sessions have improved farmers' comprehension of the responsibilities assigned to them during reforms. Second, OERTs explicitly bring together all farmers of a tertiary block, which generates a sense of group membership. Third, farmers appreciate the aspect of self-regulation established through the OERTs, in particular the fact that they can decide themselves when and how to maintain tertiary infrastructure (Etz, 2005). On the other hand, two important features might jeopardize the future of OERTs. First, the heavy structures and procedures for operating OERTs absorb much energy during their set-up and hinder rather than facilitate their functioning. Furthermore, the organizations' basis of authority is very weak, since sanctions provided in the internal code do not go beyond blame. Once again, one of the fundamental design principles for successful institutions is being violated (Ostrom, 1993). Currently, OERTs can only be successful when they are supported by a consensus of all members, and obstinate rule breaking has already led to the collapse of some OERTs. Even with material sanctions, there would have to be an effective mechanism to enforce them. Legal backing by the judicial system, as currently intended, might not be effective, since it implies a huge psychological barrier for most farmers. Indeed, many farmers reported to feel insecure or even humiliated in front of officials given the knowledge and education gap that usually exists between them.

7.4.3 Informal patterns of water management

Decision-making on water management

Two important and related principles shape decision-making. First, it is considered a matter of individual farmers; so collective rules that institutionalize consultation and coordination are rare (Chapter 5). The leading perception is indeed that when every one implements water management correctly, possible collective action problems are avoided (Bastiaens, 2005).

Second, in principle, access to water cannot be denied and maintenance duties cannot be imposed by fellow farmers. This principle results from the combination of prevalent egalitarian norms and the absence of customary law. Indeed, since the Office du Niger was constructed by the colonial power and during decades, decision-making was done exclusively by the central management, customary law regulating access and use of natural resources does not apply to the irrigation scheme. IMT has thus resulted in an open-access regime, a process comparable to the nationalization of natural resources where the state does not have the capacity to effectively manage the resource in the field (Ostrom, 1990).

In practice, farmers' decision-making is motivated by personal principles that are shaped by a trade-off between the common interest and personal costs, benefits and constraints. Regarding the cropping calendar, coordination of planting dates should avoid conflicts between irrigation and drainage at the end of the cropping season. Its cost, which consists of communication and observation of each others' farming activities, is small, especially for farmers residing in the village, where the start of the cropping season is a topic of casual conversation. However, the main motivation is the economic benefit from anticipating the planting date in order to benefit from the higher price for early harvested rice (Coulibaly *et al.*, 2002). Second comes the availability of workers and farming equipment, which limits farmers' freedom of choice regarding the start of the growing season (Keita, 2003).

As to the opening and closing of tertiary and field canal intakes, the common interest is not to overuse water or disturb fellow farmers' irrigation activities. The cost consists in information gathering on ongoing irrigation activities. Since most farmers are not present on the field during irrigation, this implies that all field intakes need to be checked, which is considered a time-consuming task. In contrast, when several farmers are present at the same time, informal exchanges on irrigation activities have been witnessed.

Maintenance is motivated above all by the fact that the aquatic weeds growing in the irrigation and drainage canals offer a habitat for the ravagers of the rice crop, such as rats and granivorous birds. In addition, degradation of the canal bed leads to leakages and frequent overflowing resulting in excess flooding of the rice fields. Since canals are over-dimensioned, decreasing water flow and storage capacity only becomes critical in case of long-term neglect. On most of the tertiary blocks, the agreement is that every farmer maintains the sections of the irrigation and drainage canals adjacent to his plot. The cost is in the first place labor input, but maintenance has a direct benefit by reducing damage by the ravagers of the rice crop.

The trade-off can result in more or less individualistic behavior, depending on how heavy the common interest is weighed. Individualistic behavior has been noted to proliferate easily, when farmers acting for the common good feel betrayed by the others. Ensuing collective action problems then remain unresolved and often lead to frictions. On the one hand, the presence of influential and motivated farmers on the tertiary block, can promote principles based on the common interest, which was confirmed in about all of the in-depth interviews with village leaders. These farmers are often, but not necessarily, canal chiefs. When they are, farmers of the tertiary block have formalized their de facto authority when the function of canal chief was created. On the other hand, when no one already possessed this authority, the appointment as canal chief could not establish it.

Even though individual decision-making is the rule, for specific events such as acute water shortage or a large breach in the canal banks, farmers of a tertiary block can engage in temporary coordination of activities. To that end, informal meetings are convened on the spot where rules are agreed upon or activities are organized to cope with the situation. Participation is voluntary in principle, but can be pushed through peer pressure. The leading characteristics of ensuing coordination are that it is spontaneous, ad hoc and specific to the situation. Interviews however revealed that not all farmers groups manage to coordinate activities, even for short periods. On about one third of tertiary blocks from the sample, it is every man for himself in all situations. Most of these tertiary blocks have slid towards this chaotic situation because some farmers defected on rules or agreements. Without a functional monitoring and sanctioning system, they could do so unpunished, which eroded trust and incited individualistic reflexes (Chapter 4). Once these attitudes prevail, it is difficult to reintroduce coordination (Cleaver, 1999). Spontaneous collective action is thus not guaranteed to arise when needed.

Conflict management

In case of conflict on water management issues, a mediator is often called upon to make a decision. Conflict management follows pre-eminently informal patterns and passes through different steps. In a first step, the mediator is an influential farmer of the tertiary block, who may or may not be the canal chief. For 29 of the 36 tertiary blocks studied, most conflicts are settled at this level. For the other tertiary blocks, or when no agreement could be reached, an influential person at the village level is contacted. In seven of the nine villages of the case study, that person is the village chief. The village chief can either take a decision himself (5 villages), or call upon someone he judges more competent on the matter, such as the water guard, to whom he lends his authority (2 villages). Decisions taken at this level are normally followed. The village chief derives his authority from the respect that villagers grant him and from popular consent. Consequently, he has to act in the common interest of the village if he wants to maintain this authority. In general, this authority over non-resident farmers is much weaker or even inexistent. In the case the village chief does not interfere with conflicts on water management, another influential person at the village level is sought, such as the president of the village cooperative or the water guard. The following step is the central management of Office du Niger, even if it is not formally competent to settle these matters. This step is only taken in the case of serious and persistent conflicts. The central management is generally seen as a neutral agent and its decisions are respected, but it does not dispose of fixed procedures for conflict settlement, which makes its officials reluctant to get involved. In an ultimate step, which implies an even greater barrier, the conflict might be reported to the police or judicial system where a formal decision is pronounced. Up until today, WUAs do not play a role in conflict management, even though their leaders might be involved as a private person because of their personal authority.

Information transfer

No less than conflict management, information transfer follows informal patterns. Three levels of information transfer on water management are distinguished. The first concerns information on water management decisions at tertiary block level, where information gathering is an individual matter and is done through observations and personal contacts. Centralization of information does not take place. The next level concerns information transfer between farmers and the water guard regarding water supply and demand at the tertiary canal intake. Current strategies are to reduce the need for information transfer by maintaining an excess supply in the canals (Chapter 3). When information transfer does take place, it concerns specific demands of individual farmers and is done either directly or through the canal chief or head of the CPP. Centralization of information by the canal chief, as was originally intended, seldom occurs. The third level regards information transfer between farmers and the central management, which implies surpassing the village level. In general terms, the village chief is the pivot of information entering or leaving the village, and this is no different for water management. When farmers need to contact the central management, they go and see the village chief, who sends an intermediary to the central management. Likewise, when the central management wants to circulate information among farmers, they contact the village chief, who convokes a meeting to pass on the information.

Formal pattern of information transfer designed in the scope of WUAs at the village level is thus completely disregarded (Figure 7.1). Informal patterns in use nevertheless show several flaws. First, at the first and second level, information transfer is not institutionalized, meaning that (1) there is no rule which says that information should be shared and (2) there are no predetermined routes to circulate information which increases the probability that someone is not reached. Consequently, information transfer is incomplete at these levels. Next, at the third level of information transfer, non-resident farmers form a missing link, since they are out of touch with village level events. Their not being informed often creates frustration for both the non-residents themselves, for example when they are not informed on a temporary cut in water supply, and for others, when non-residents do not follow certain instructions they are not aware of.

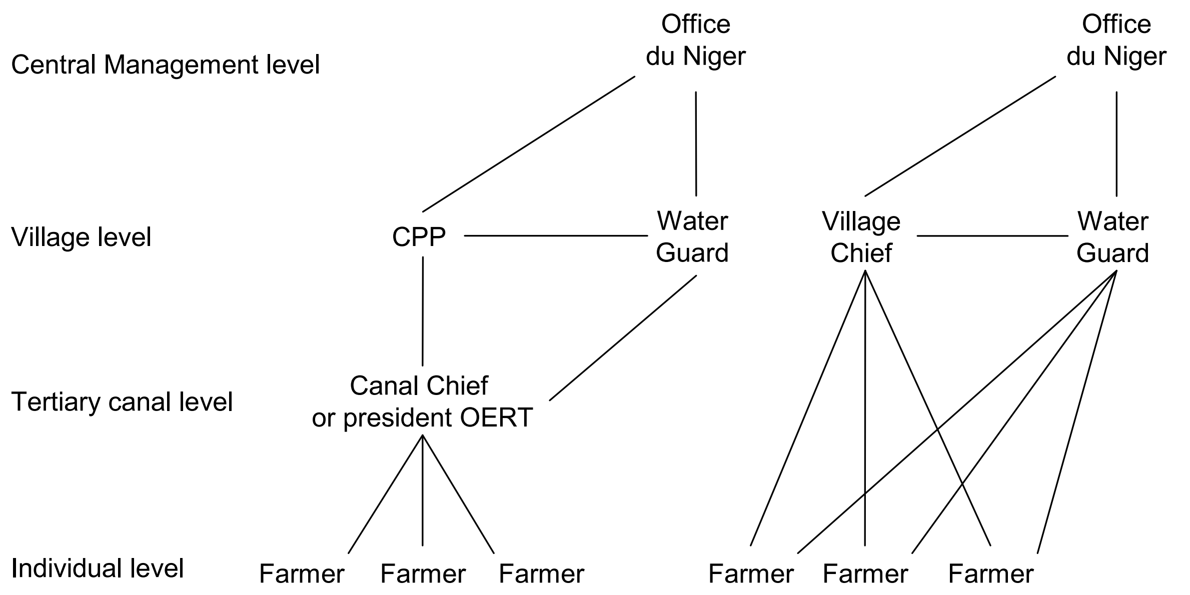


Figure 7.1 Formal (left) and informal (right) patterns of information transfer

Finally, in villages where the village chief is involved in a dispute between different factions, he can no longer be the pivot of information transfer, as is the case in Médina and Medina-Coura. When the central management is aware of the situation, they often try to contact various leaders within the village, which in itself is a time consuming task. Even then, the information might not reach some farmers, creating frustration as described above. Informal patterns of information transfer are thus incomplete and vulnerable to disruption. As such, they are an excellent example of how informal institutions are not necessarily better than the proposed formal ones (Cleaver, 1999). It rather illustrates that a power transfer from local informal but strong institutions to a new legality is hard to achieve when the informal institutions are completely sidetracked (Onibon *et al.*, 1999; Ribot, 1996).

7.5 Recommendations to improve the success of WUAs in the Office du Niger

In the Office du Niger, WUAs were set up to fill the power vacuum left by IMT but did not live up to expectations. First, they lack sanctioning mechanisms to make them credible. Second, by providing heavy procedures, costs of the WUAs are disproportionately high with respect to benefits. Third, the socio-cultural reality, in itself the result of the irrigation scheme's historical track, has been disregarded. In particular, the fact that farmers do not accept the authority of fellow farmers for water management underlines the need of external sources of authority. Meanwhile, decision-making on water management continues to follow existing informal patterns. These are rather successful concerning conflict management, but show considerable deficiencies in coordinating decision-making and information transfer. In this context, WUAs could give the necessary impetus for strengthening water management, given that farmers effectively adopt them. Indeed, when all farmers of a tertiary block are involved in the WUA, it offers a much-needed platform for institutionalizing collective action.

In view of the analysis of the role of WUAs and informal patterns of decision-making in water management, several recommendations can be formulated to improve the success of WUAs.

1. Structures and procedures of WUAs should be kept as simple as possible. In addition, their objectives should respond to actual needs. These lie essentially in institutionalizing and facilitating information transfer reaching all farmers and enhancing collective action when problems occur. Activities of WUAs should thus be allowed to be spontaneous and specific to the situation, and formal structures should merely facilitate these activities. This implies that the internal code is drawn up by the members of the WUA and provides necessary flexibility and legitimacy for ad hoc agreements.

2. In order to enhance their legitimacy, support of village leadership -in particular the village chief- should be considered. In this way, WUAs will be able to take advantage of existing patterns of conflict management, which are mostly effective. This support can be obtained by convincing village leadership of the importance of WUAs, and the importance of their involvement. Separate meetings with village authorities are thus needed before establishing the WUAs. Next, village authorities should be involved during the set-up of WUAs, for example, by asking them to preside at the set-up meeting, together with the extension agent in charge.

3. A water tight sanctioning system is needed, considering the growing presence of farmers and leaseholders that are non-resident farmers and fall outside the sphere of influence of the village chief. Farmers should thus be incited to provide financial or other sanctions when infractions are observed. When disputes over sanctions arise that cannot be solved within the WUA or at the village level, the WUA should be able to appeal to the central management for final settlement. The latter should then be able to appeal to fixed procedures for conflict settlement.

The mechanism currently promoted, which involves the judicial system, is considered to imply too large a barrier for ordinary farmers to be effective. The central management however is closer to farmers while possessing the necessary authority. Given the current trend toward devolution of water management, this might seem as a step backwards. However, considering that on the moment of IMT, no customary or other forms of organization at farmers level were in place, it might be premature to completely discard it.

7.6 Conclusions

In irrigation schemes around the globe, WUAs are being created to replace the central management as the center of decision-making on water management. The importance of user participation and the involvement of informal institutions are recognized in theory. In practice, WUAs are however often imposed on farmers in a top down way, bypassing existing informal patterns of decision-making. Consequently, many WUAs do not fulfill their intended role. From the Office du Niger case study, several lessons can be learned.

First, the involvement of existing sources of authority is indeed crucial for new legalities to work, especially in situations where authority is hard to establish. In the Office du Niger, and more generally in an African context, the village level provides such a source of authority. In this study, it was observed that performance of WUAs is strongly linked with the support of the village chieftaincy. Another important source of authority is the central management, which WUAs are nevertheless meant to replace. Indeed, in irrigation schemes where customary leadership has been stunted for decades, the central management might still be considered the only legitimate leader even after management transfer. In that case, collaboration between the central management and WUAs might be more useful than a model of antagonism. This implies that national governments, NGOs and international donors that usually promote WUAs should be prepared to give priority to existing informal principals of governance and centers of authority, even when they contradict their own principles of democratic representation.

Second, informal decision-making on water management is not always fully understood, which makes it impossible to take it into account. Active farmer participation in the design of WUAs provides part of the answer. However, there is also a role for researchers to accompany the creation WUAs to make local realities explicit. As such, they can facilitate the dialogue between farmers and the policy level.

Box 9 The multiple users of the irrigation scheme

The land, water and infrastructure of the Office du Niger are destined to irrigated agriculture. In practice, there are many other users besides farmers. At the tertiary block level, herdsmen and fishermen are the most important ones. Herdsmen water their herds in the tertiary canals and feed them on weeds and rice stubbles of fallow fields. They furthermore use the roads on the dikes to transport their cattle. In doing so, they often damage the canals and contour dikes, fostering water losses through leaks and breaches. Fishermen stretch their nets across the tertiary canals and sometimes open canal intakes in order to create a water flow. As such, they contribute to the excess water supply.

So far, their role is not formally recognized, and they have no responsibilities or liabilities towards farmers or the central management. Consequently, the externalities created by herders and fishermen are born by the farmers only. As the irrigation scheme is generally considered as an open-access regime, farmers feel they cannot deny the right of entry to their tertiary block. In addition, herders and fishermen form highly variable groups whose members are difficult to identify. They do not systematically use the resources of the same tertiary block and are often outsiders to the village. As such, they are unknown to each other and to the farmers and village chiefs have little or no authority over them. This situation often leads to grudges and conflicts. These might further gain in amplitude as incentives are created for increasing irrigation efficiency. It will therefore be necessary to start a dialogue between the representatives of the different user groups in order to clearly define the rights obligations for each of them.

Chapter 8
The prospects for farmers' water management: motivation for collective action

Abstract[1]

The present chapter studies the prospects for farmers' water management based on their motivation for collective action using empirical data. The study is based on a statistical analysis of empirical data from the Office du Niger irrigation scheme, where Irrigation Management Transfer made farmers responsible for water management at the tertiary level. This transfer was part of a broader reform package, which has opened up economic opportunities. The study shows that farmers are diversifying their income at the expense of agricultural activities and rice farming in particular. This trend brings along an increased employment of wage laborers, who have water management among their tasks. It appears however that wage laborers are far less motivated to cooperate with fellow farmers, which might jeopardize the prospects for farmers' water management. Based on the analysis, some policy recommendations are formulated.

8.1 Introduction

As a result of Irrigation Management Transfer (IMT), farmers need to establish collective action to deal with their common responsibilities. The success of collective action for the management of Common Pool Resources, such as collective irrigation schemes, depends on the trade-off between costs and benefits at the level of the user group and individual users

[1] This chapter is adapted from: Vandersypen, K., Bastiaens, L., Traoré, A., Diakon, B., Raes, D., and Jamin, J.-Y. (In Press). The prospects for farmers' water management: motivation for collective action in the Office du Niger irrigation scheme (Mali). Irrigation and Drainage.

(Ostrom, 1992). At the group level, this trade-off is determined by the characteristics of the resource, the user group and institutional arrangements (Dayton-Johnson, 1999). Social norms and values, such as reciprocity, trust and fairness, also play a role as they can favor cooperation (Ostrom, 2000). At the individual level, the trade-off between perceived costs and benefits influence users' motivation to participate in collective action. This can be attributed to economic dependence on the CPR (Adhikari *et al.*, 2004), understanding and knowledge about the CPR (Baticados, 2004), and social and demographic characteristics such as age, gender, class and economic position (Futemma *et al.*, 2002). This chapter investigates the socio-economic determinants of farmers' motivation for collective action for the Office du Niger irrigation scheme.

Until today, water in the Office du Niger is not scarce during the main growing season. Still, collective action for water management can be useful or even necessary. Firstly, coordination at the intake of the tertiary canal avoids over-supply of water to the tertiary canal. An over-supply increases the risk of breaches and overflows in the tertiary canal, leading to excessive flooding of rice fields. Next, excess water saturates the drainage system, causing drainage problems at harvest. Second, allocation rules avoid irrigation problems after a disruption of water supply at the secondary level (Chapter 5). The importance of collective action will furthermore increase with time. The Office du Niger has started an impressive expansion, aiming to more than double the irrigated area by 2020. As water will become scarce, coordination of supply and demand at the intake of the tertiary canal will be necessary to increase irrigation efficiency. Until today, collective action at the tertiary block level seems difficult to establish in the irrigation scheme (Chapter 4). As farmers adjust to their new responsibilities, a mentality shift towards assuming collective responsibility for water management might take place. This will favor the trade-off between costs and benefits of collective action at the group level. In order to stimulate this process, continuing efforts aim to enhance collective action by means of sensitization and information sessions on the one hand, and institution and capacity building on the other hand. Recent dynamics might however thwart this evolution through their negative influence on the trade-off at the individual level. Indeed, during the 1990s, economic reforms and technical improvements in rice farming contributed to a considerable rise in farmers' purchasing power (Mariko *et al.*, 2000). The ensuing economic expansion has increased non-agricultural employment, for example in retail trade and artisanship. Many plot holders are diversifying their sources of income at the expense of agricultural activities and in particular rice farming. For some, rice farming becomes a secondary occupation. Furthermore, the expansion of the irrigated area, together with a decrease in plot size to promote intensification of rice production, has opened up land for new beneficiaries. Many of these already have a job outside agriculture, often as staff members of the central management or civil servants, and consider rice farming a secondary occupation. This evolution is expected to jeopardize the prospects for farmers' water management. Indeed, plot holders who diversify their sources of income at the expense of rice farming reduce their stake in their rice plot. Therefore, it is assumed that they might become less interested in water management, and consequently less motivated for collective action. Furthermore, they are expected to rely more on seasonal wage laborers substituting family labor, when the latter concentrate on other activities. The latter are in turn also expected to be less motivated for collective action for water management.

In order to gain insight in the determinants of motivation for collective action, these effects are evaluated using survey data. The analysis proceeds in the following steps: First, the socio-economic determinants of farmers' interest in rice farming are assessed. Since interest in rice farming is expected to influence interest in water management, it is added to the list of socio-economic variables to predict interest in water management. Next, the impact of the determinants and interest in rice farming and water management on farmers' motivation for water management and the employment of seasonal wage laborers are evaluated. Finally, the motivation for collective action of farmers and seasonal wage laborers are compared.

8.2 Methods

Data are drawn from a questionnaire survey on farmers' attitudes towards water management conducted in 2004, which is described in detail in Bastiaens (2005). The survey covered 11 villages from the Niono, Molodo and N'Debougou zones. 150 plot holders were selected randomly from the pay roll for water fees and were contacted with the help of the village chief, fellow farmers and other key informants. 48 plot holders from the sample are non-resident farmers of which 24 plot holders were not known by the informants and could not be contacted. A trained interviewer administered the interviews. The questionnaire was presented to the person who is responsible for the actual cultivation of the rice plot within the family, called chief of operation, as indicated by the plot holder. The chiefs of operation are usually the plot holders themselves or an adult (male) family member. In a follow-up survey conducted in 2005, the same interviewer presented the questionnaire to fifty-one wage laborers employed by the plot holders from the 2004 survey. For detailed information on the follow-up survey, see Traoré (2006). The questionnaire was constructed in French and translated into Bambara using the translation-back-translation technique (Brislin *et al.*, 1973). After a testing phase, several questions were reformulated to improve respondents' understanding. Closed questions were used to allow for statistical analysis. Crosschecking answers to specific questions allowed the detection of inconsistent responses. As such, twenty-six cases were eliminated from the sample of plot holders, setting their final sample size at 100. The average responses to key questions on farmers' attitudes of the twenty-six eliminated cases did not differ significantly from the remaining sample averages of 100 cases.

Table 8.1 Sample characteristics[a]

Particulars	Chiefs of operation[b]	Seasonal wage laborers[b]	Office du Niger average[c]
Size of the rice plot (ha)	3.5 (2.7)	-	2.6 (-)
Number of persons living from the farm	13 (7.4)	-	-
Employment of > 4 family workers	40%	-	-
Principal activity is rice farming	44%	-	-
Non-resident farmers	21%	-	33%
Village within the Office du Niger area	12%		18%
Town within the Office du Niger area	9%	-	10%
Outside the Office du Niger area	0%	-	5%
Member of a cooperative	88%	25%	71%[d]
Non-executive member	63%	7%	-
Executive member	25%	18%	-
Age (years)	43 (12)	30 (12)	49 (15)
Number of generations			
First generation	18%	-	-
Second generation	75%	-	-
Third generation	7%	-	-
Position of the plot			
Top end position	30%	-	-
Middle position	35%	-	-
Tail end position	35%	-	-

[a] Numbers between brackets represent standard deviations
[b] Survey data
[c] survey of 2571 plot holders in 33 villages (Bélières *et al.*, 2003)
[d] Only village cooperatives, excluding Economic Interest Groups (GIEs) and farmers' syndicates

Sample characteristics are presented in Table 8.1. Non-resident plot holders, and particularly those living outside the Office du Niger irrigation scheme, are underrepresented in the survey sample. For non-resident plot holders, rice farming is more often a secondary activity (Bélières *et al.*, 2003). It is furthermore expected that non-resident plot holders employ more seasonal wage laborers and are less motivated for collective action for water management. Judgments based on the survey sample should thus be interpreted with care. Differences in average age of chiefs of operation from the survey sample (average = 43 years) and plot holders in the total research population (average = 49 years) can be partly attributed to the fact that chiefs of operation who are not plot holder are generally younger (average = 30 years; n = 11). The statistical analyses are based on the binary logistic regression model and Pearson Chi-square test. The analyses are performed using the SPSS computer package.

8.3 Socio-economic variables

The socio-economic variables used in the statistical models are related to the current economic dynamics in the Office du Niger irrigation scheme. This section explains how they have been operationalized and selected. Table 8.1 presents summary statistics for the independent variables.

Farm size

Farm size contains three distinct aspects: (1) plot size, (2) number of persons living from the farm, and (3) number of family members working at the farm. It is expected that the larger the farm, the larger the farmer's stake in rice farming, which in turn is assumed positively related to interest in rice farming and water management and motivation for collective action. The average plot size has decreased from over ten hectares in the early 1970s to about two hectares nowadays. There are several reasons for this sharp decline. First, in order to stimulate intensification of rice farming, a reduction in plot size accompanied rehabilitation of the irrigation infrastructure (Aw and Diemer, 2005). Next, in the second and third generation, many families divided the farm between the heirs, further reducing plot size (Keita, 1998). Moreover, in view of the considerable pressure on irrigated land in the Office du Niger, the average plot size in newly developed areas is often less than a hectare (CEFE Consultants, 2004). The trend of reducing plot size is thus expected to persist in the foreseeable future, with a possible negative impact on interest in rice farming and water management and motivation for collective action. Regarding the employment of wage laborers, if they supplement family labor, it is assumed that they are employed more frequently on farms with a large plot size. On the other hand, if wage laborers substitute family labor, they are expected to be found more frequently on farms with a small number of family workers. The plot size is indicated on the pay roll for water fees and was verified during the survey. The number of persons living from farm income and the number of family members working at the farm were furthermore assessed during the survey. Many respondents appeared to have considerable difficulties counting the number of family members working at the farm precisely, especially when many family members contributed. Indeed, the family labor force is not stable throughout the growing season. Instead of a quantitative variable, it was chosen to use the more robust dummy variable assessing whether yes or no, more than four family members work at the farm.

Dependence on rice farming

In the Office du Niger irrigation scheme, virtually all farmers have diversified their income, mostly in vegetable farming, livestock or trading (Bastiaens, 2005). The survey assessed on which of these activities (1) the chief of operation spends most of his time, and which (2) generates most income at the family level. The assumption is that when other sources of income require more time for the chiefs of operation, they will be less interested in rice farming and water management and less motivated for collective action. Likewise, having less time available for rice farming, they are assumed to employ more often wage laborers. The main source of income is expected to influence above all motivation for collective action: the less a farmer's income depends on the collective resource, the less he is expected to be motivated for collective action (Ostrom, 1992). A second indicator for dependence on rice farming and assessed in the survey is the family's place of residence. As they do not interact in daily life outside rice farming, non-resident farmers are less subject to peer pressure from their colleagues, which might reduce their motivation for collective action. In addition, some of the non-resident farmers live in one of the small towns in which most commercial activities within the area of the irrigation scheme are concentrated. These farmers have more opportunities to opt out of rice farming than farmers living in a village have and are therefore assumed to be less interested in rice farming and water management and even less motivated for collective action. Furthermore, given the distance that separates them from their plot, they are expected to employ more wage laborers. The place of residence is assessed during the survey and compared to the village nearby the plot.

Membership of a cooperative

In the process of economic liberalization in the irrigation scheme in the 1980s, international donors created village cooperatives to manage agricultural input supply, and processing and marketing of production. Because of mismanagement, about one third of these cooperatives went bankrupt and ceased to exist. Meanwhile, groups of farmers have autonomously created so-called Economic Interest Groups (GIEs) to replace or compete with existing cooperatives, and in the sample villages, either a village cooperative, GIE or both are present. Members of a cooperative are assumed more inclined towards collective action, since they already cooperate in other circumstances. This should be even more the case for executive members, i.e. those who hold a position in the cooperative such as president, secretary or treasurer. In the survey, membership of a cooperative, and the position in it were assessed. As the vast majority of cooperatives are farmer organizations, membership might furthermore imply strong involvement in rice farming, translating in a higher interest in rice farming and water management.

Demography

Two demographic variables were assessed during the survey: the age of the chief of operation and whether his father or grand father already was a farmer in the Office du Niger (translated in first, second or third-generation farmer). Younger people are expected to be more open to alternative economic opportunities and therefore less interested in rice farming and water management. Furthermore, popular consent has it that they are less courageous for working on the field, which might further reduce their interest in water management and collective action and increase the probability to employ wage laborers. Regarding generation, it is assumed that second and especially third-generation farmers are more firmly rooted and experienced in rice farming and water management and therefore more likely to be interested in it. Since their interaction with fellow farmers is extended over the generations, they are in addition assumed more motivated for collective action.

Position of the plot

The position of the plot on the tertiary canal is expected to have an impact especially on farmers' motivation for collective action. A crucial aspect of collective action is gathering and sharing information about ongoing irrigation activities at the tertiary block. Since tertiary canals are about 750 to 1,000 m long, and most farmers are not present on the field during irrigation, this is a time-consuming task and therefore costly (Chapter 7). Thanks to their central position, information gathering and sharing is easier and thus less costly for farmers whose plot is located in the middle. They are therefore expected to be more motivated for collective action than their colleagues at top end or tail end plots.

Selection of variables

Because of the presence of correlations within the group of socio-economic variables, a selection was carried out in order to obtain a final set for statistical analysis. First, the three variables of farm size are strongly positively correlated. Since plot size and the variable assessing the number of family members working at the farm are expected to have a different effect on the employment of wage laborers, both are kept as variables, while the number of persons living at the expense of the farm is excluded. Next, the place of residence is strongly related to membership of a cooperative. Indeed, virtually all of the resident farmers are members, while only two thirds of non-resident farmers are. Since membership of a cooperative is expected to have a specific effect on motivation for collective action, it is selected as a variable and place of residence is not. Lastly, regarding the dependence on rice farming, chiefs of operation who spend most of their time on rice farming usually derive also most of their income from it. Because the combined effect is expected to be stronger than the effect of the individual variables, a dummy variable for the main activity is used with value one if both are true and zero otherwise. The dummy variable is in turn related to plot size, with values of one being more frequent for larger plots. Both are however kept as variables because they are considered to contain supplementary information. Contrary to what might be expected, generation and age are not significantly related. Indeed, farmers continue to settle in the irrigation scheme since the early 1940s, so that some first generation farmers are still relatively young, and some third generation farmers might already relatively old. Contrary to what might be expected, generation and age are not significantly related. Indeed, farmers continue to settle in the irrigation scheme since the early 1940s, so that some first generation farmers are still relatively young, and some third generation farmers might be relatively old.

8.4 Results from the statistical models

8.4.1 Interest in rice farming

Interest in rice farming is measured by asking chiefs of operation in which activity they would invest additional time and money. Responses are categorized in a dummy variable with a value of one if the respondent opted for rice farming and zero otherwise. Since the maximum production per area of land is not yet reached in the Office du Niger irrigation scheme (Haefele *et al.*, 2003), extra time and money could be invested in the rice plot in order to increase yields, which would be an indicator for a farmer's interest in rice farming. Results indicate that only 38 % of the chiefs of operation from the sample would give priority to rice farming for investing extra time and money (Table 8.2).

Significant determinants are age, the actual main activity, and generation, with postulated hypotheses being confirmed. This implies that, once a farmer has moved away from rice farming as a main activity, as many younger ones would prefer, the odds of returning are small. Under the current circumstances, a trend of farmers' declining interest in rice farming can thus be expected. This is an important conclusion in itself. The Office du Niger already deals with 56 % part-time farmers (Table 8.1), a proportion that is likely to increase further. In addition, this trend might negatively influence farmers' interest in water management and the success of collective action for water management at farmers' level. The expected negative impact of plot size is not significant in the model, even though the average plot size is smaller for chiefs of operation who give priority to other activities than rice farming.

Table 8.2 Determinants of the probability of priority for rice farming in investment decisions

Independent variables	Parameter estimates		Sample descriptives[2] according to priority for investment in rice farming	
	B	Exp(B)	Yes	No
Total			38%	62%
Middle position of plot on the tertiary canal[1]	0.690	1.993	39%	32%
Tail end position of plot on the tertiary canal[1]	0.666	1.946	37%	34%
Plot size (ha)	0.115	1.121	3.9 (2.8)	3.2 (2.5)
Age (years)	0.062***	1.064	46 (12)	41 (11)
Employment of > 4 family workers	-0.808	0.446	39%	40%
Member of a cooperative[1]	0.088	1.091	89%	87%
Executive member of a cooperative[1]	0.599	1.820	26%	24%
Principal activity (1 if rice farming, 0 otherwise)	1.317**	3.732	66%	31%
Second-generation farmer[1]	1.647**	5.193	76%	74%
Third generation farmer[1]	4.146***	63.178	16%	2%
Model constant	-6.107***	0.002		

Likelihood ratio index = 101.280***
Nagelkerke R square = 0.368
% correctly predicted = 75
** Significant at 0.05 probability level
*** Significant at 0.01 probability level
[1] Increase or decrease in the value of the model constant compared to the reference category
[2] Numbers between brackets represent standard deviations

8.4.2 Interest in water management

In principle, the chief of operation takes all strategic and day-to-day management decisions regarding the rice plot. Likewise, important or delicate tasks are typically implemented by the chief of operation, while routine or more cumbersome tasks are left to other family members or seasonal wage laborers. The person responsible for decision-making and implementing water management is thus a good indicator for interest in water management. As irrigation is one of the principal activities of water management throughout the growing season, the survey assessed (1) who decides on the time and volume of irrigation, and (2) who puts it into practice. The dependent variable used in the model is a dummy with a value of one if both decision-making and implementation are done exclusively by the chief of operation and a value of zero otherwise.

Table 8.3 Determinants of the probability of irrigation activities being performed by the chief of operation

Independent variables	Parameter estimates		Sample descriptives[2] according to irrigation being performed by the chief of operation	
	B	Exp(B)	Yes	No
Total			48%	52%
Middle position of plot on the tertiary canal[1]	-0.224	0.799	33%	37%
Tail end position of plot on the tertiary canal[1]	-0.300	0.741	35%	35%
Plot size (ha)	-0.343***	0.710	2.8 (2.2)	4.0 (3.0)
Age (years)	0.022	1.023	45 (12)	41 (12)
Employment of > 4 family workers	0.589	1.802	42%	38%
Member of a cooperative[1]	1.715*	5.559	96%	81%
Executive member of a cooperative[1]	2.264**	9.623	29%	21%
Principal activity (1 if rice farming, 0 otherwise)	0.040	1.041	46%	42%
Second-generation farmer[1]	1.347**	3.847	81%	69%
Third generation farmer[1]	1.775	5.898	8%	6%
Priority for rice farming in investment decisions	0.617	1.854	46%	31%
Model constant	-3.028*	0.048		

Likelihood ratio index = 114.687**
Nagelkerke R square = 0.282
% correctly predicted = 68
* Significant at 0.1 probability level
** Significant at 0.05 probability level
*** Significant at 0.01 probability level
1 Increase or decrease in the value of the model constant compared to the reference category
2 Numbers between brackets represent standard deviations

About half of the chiefs of operation from the sample still both take decisions and implement them personally (Table 8.3). In reality, this figure might be lower, as non-resident plot holders, who are underrepresented in the sample, probably more often leave irrigation to others. Results from the binary logistic model show that, contrary to the expectations, this is more frequent on farms with a larger plot size. The reason might be that on large farms, it is simply impossible for the chief of operation to assume irrigation activities all alone. Other significant variables are membership of a cooperative and generation, whose impact is in line with the hypotheses. Ultimately, chiefs of operation for whom rice farming is not a priority, more often leave decision-making and/or implementing irrigation to others. The parameter in the model is not significant, but this might be due to its relation with other significant parameters, such as generation. If only half of chiefs of operation are responsible for irrigation nowadays, this figure might further decline as interest in rice farming decreases over the years. Water management is thus not a major concern for farmers.

8.4.3 Motivation for collective action for water management

In this study, farmers' willingness to introduce coordination of demand and supply at the tertiary canal intake is used as an indicator for motivation for collective action. This is an important aspect of collective action under the present circumstances of water abundance, since it can avoid over-supply of water to the tertiary block and its negative consequences. Furthermore, as water becomes more scarce due to the ongoing expansion of the irrigated area, this coordination will be essential to improve irrigation efficiency (Chapter 5). It is usually put into practice by an influential farmer, who collects information on water demand of fellow farmers and coordinates the opening and closing of the tertiary canal intake. According to the guidelines of the central management, this is the task of the tertiary canal chief, who is elected by the farmers of the tertiary block. All farmers however need to cooperate with this system by collecting and sharing information. In practice, coordination of water supply and demand takes place in about one third of tertiary blocks (Bastiaens, 2005). Respondents could be incited to answer positively on a direct question on whether the respondent would like coordination introduced because of political correctness. Therefore, the questionnaire featured a more open question asking what are, in the opinion of the respondent, the tasks a canal chief should perform. Next, a dummy variable was used with a value of one when both collecting information on individual farmers' water demand and coordination of the tertiary canal intake were mentioned among the tasks and a value of zero otherwise.

About 65 % of the chiefs of operation from the sample would like the canal chief to coordinate water supply and demand at tertiary block level, meaning there is quite a good potential for collective action (Table 8.4). The binary logistic regression model predicting the probability of favoring this coordination has only two significant variables. As expected, chiefs of operation from larger plots and at the middle position of the tertiary canal are more often in favor of coordination. Furthermore, the model is not significant as a whole, meaning the set of independent variables is not adequate to explain the probability of favoring coordination. In other words, farm characteristics say little about farmers' motivation for collective action. Nevertheless, even though the model parameters are not significant, chiefs of operation who would not give priority to rice farming for investing extra time and money, as well as those not taking on decision-making and implementation of irrigation activities, are less likely to be in favor of coordination. This might imply that as interest in rice farming and water management decline as is suggested by the results, motivation for water management also decreases. On the other hand, in view of the results on interest in water management, the motivation of the chiefs of operation might be of decreasing relevance. Indeed, only half of them are actually responsible for decision-making and implementation of irrigation, these tasks often being left to seasonal wage laborers. Consequently, the motivation of the latter is equally pertinent for the prospects of collective action.

Table 8.4 Determinants of the probability of favoring coordination of water demand and supply at tertiary block level

Independent variables	Parameter estimates		Sample descriptives[2] according to the respondent favoring cooperation	
	B	Exp(B)	Yes	No
Total			65%	35%
Middle position of plot on the tertiary canal[1]	1.550**	1.601	43%	20%
Tail end position of plot on the tertiary canal[1]	.626	0.793	32%	40%
Plot size (ha)	.216*	1.173	3.7 (2.8)	3.1 (2.5)
Age (years)	.024	1.026	43 (12)	43 (13)
Employment of > 4 family workers	-.885	0.846	35%	49%
Member of a cooperative[1]		1.396	86%	91%
Executive member of a cooperative[1]	-.056	1.740	23%	29%
Principal activity (1 if rice farming, 0 otherwise)	-.155	1.965	46%	40%
Second-generation farmer[1]	.300	1.310	75%	74%
Third generation farmer[1]		1.033	5%	11%
Priority for rice farming in investment decisions	-.085	0.457	35%	43%
Irrigation activities are performed by the chief of operation	-1.508	0.541	40%	63%
Model constant	-.611	0.252		

Likelihood ratio index = 111.546
Nagelkerke R square = 0.226
% correctly predicted = 71
* Significant at 0.1 probability level
** Significant at 0.05 probability level
[1] Increase or decrease in the value of the model constant compared to the reference category
[2] Numbers between brackets represent standard deviations

8.4.4 Employment of seasonal wage laborers

The employment of seasonal wage laborers was assessed during the survey of chiefs of operation. A dummy variable was used with a value of one if any seasonal wage laborers are present and a value of zero otherwise. From the results, it appears that 35 % of chiefs of operation from the sample employ seasonal wage laborers (Table 8.5). In reality, this figure might be higher, since plot holders living outside the Office du Niger area are hardly ever present in the irrigation scheme and usually rely on wage laborers to cultivate their plot.

Indeed, if all plot holders living outside the Office du Niger area from the initial sample of 150 cases employ wage laborers, the figure would rise to 47%.

Table 8.5 Determinants of the probability of employing seasonal wage laborers

Independent variables	Parameter estimates		Sample descriptives[2] according to the employment of wage laborers	
	B	Exp(B)	Yes	No
Total			35%	65%
Middle position of plot on the tertiary canal[1]	-0.743	0.476	29%	38%
Tail end position of plot on the tertiary canal[1]	0.405	1.499	37%	34%
Plot size (ha)	0.628***	1.874	4.5 (3.3)	2.9 (2.1)
Age (years)	0.013	1.013	41 (12)	44 (12)
Employment of > 4 family workers	-3.356***	0.035	26%	48%
Member of a cooperative[1]	-0.026	0.974	86%	89%
Executive member of a cooperative[1]	1.965**	7.135	37%	18%
Principal activity (1 if rice farming, 0 otherwise)	-1.324*	0.266	37%	48%
Second-generation farmer[1]	-0.883	0.413	69%	78%
Third generation farmer[1]	-0.907	0.404	6%	8%
Priority for rice farming in investment decisions	-0.403	0.668	34%	40%
Irrigation activities are performed by the chief of operation	-1.261**	0.283	29%	58%
Model constant	-0.616	0.540		

Likelihood ratio index = 85.012***
Nagelkerke R square = 0.494
% correctly predicted = 80
* Significant at 0.1 probability level
** Significant at 0.05 probability level
*** Significant at 0.01 probability level
[1] Increase or decrease in the value of the model constant compared to the reference category
[2] Numbers between brackets represent standard deviations

The opposite effect of plot size and the number of family members working on the plot on the probability of employing seasonal wage laborers confirms the presence of two distinct strategies: supplementing family labor with wage labor on the one hand, and substituting family labor by wage labor on the other hand. Further, it appears that when the chief of operation is an executive member of a cooperative, he is more likely to employ wage laborers, which is contrary to intuition. A possible explanation could be that executive members are generally wealthier than regular members or non-members, and therefore can more easily afford to hire wage laborers. However, this explanation remains to be tested. Finally, the odds of employing seasonal wage laborers are much larger when rice farming is not the principal activity of the chiefs of operation as well as when the latter leaves decision-making and implementing irrigation to others. This might imply that, since in view of the results from the previous models, a trend of declining interest in rice farming and water management is expected, the number of wage laborers will rise over the coming years. Indeed, a differentiation in the agricultural work force emerges in the Office du Niger irrigation scheme, with on the one hand chiefs of operation, whose family holds the title to the plot, and on the other hand seasonal wage laborers who actually work on the land. This differentiation might jeopardize the prospects for collective action, as those who implement water management are not the same as those responsible for it.

8.4.5 Farmers' versus wage laborers' motivation for collective action

Table 8.6 features the proportion of chiefs of operation and seasonal wage laborers in favor of coordinating water demand and supply at tertiary block level. It seems that a much smaller fraction of wage laborers would favor coordination of water supply and demand at the tertiary level compared to the sample of chiefs of operation. This difference might root in the fact that they do not have a long-term perspective, as can be expected from the wage laborers. Indeed, most have already worked on different rice plots and remain on a plot for only about three years. Furthermore, many of them are seasonal migrants and thus are no part of the social tissue of the village. In addition, relatively few are members of a cooperative (Table 8.1). Lastly, being paid a fixed amount (Traoré, 2006), most seasonal wage laborers do not benefit from an increased production, and consequently have fewer incentives to invest time and effort to optimize production. With the number of seasonal wage laborers increasing under the current trends, and their being less motivated for collective action, prospects look rather grim and a specific policy response is needed.

Table 8.6 Proportion of chiefs of operation and wage laborers in favor or not in favor of coordinating water supply and demand at tertiary block level

	In favor of coordination	Not in favor of coordination	Total
Chiefs of operation	65%	35%	100
Wage laborers	43%	57%	51
Total	58%	42%	151

Pearson Chi-square value = 8.512, df = 2, p = 0.014

8.5 Conclusion and policy recommendations

A spectacular rise in economic opportunities in the Office du Niger irrigation scheme has set off a trend towards diversification of income. Farmers, whose sole occupation used to be rice farming, are now part-time farmers with different activities in their portfolio that might even take up more time or produce more income than rice farming. Results from this study suggest that the number of part-time farmers, who already take up about half of the farmer community, will further increase. Indeed, especially young chiefs of operation want to move away from rice farming and once rice farming is no longer the principal activity, they are not likely to return. At the same time, only half of the farmers, and even less in the case of part-time farmers, implement water management personally, the other half leaving seasonal wage laborers in charge. Nevertheless, two thirds of chiefs of operation favor collective action for water management. More important is however the confirmation of a trend towards increasing employment of seasonal wage laborers, who are less motivated for collective action.

Two policy recommendations follow from the analysis:

1. *Seasonal wage laborers as a target group*: A first implication concerns the identification of relevant target groups for efforts aiming to enhance collective action through sensitization and transfer of information. Until now, seasonal wage laborers are entirely by-passed, whereas they are in fact most in need of them. Second, they are ignored by the Water User Associations being set up at tertiary block level to establish rules and regulations for water management. Consequently, their role in water management is not taken into account, and wage laborers usually are not aware of agreed rules and regulations so that it is difficult to hold them accountable for their actions.

2. *Agricultural policy supporting full-time rice farming*: The results of this study raise questions about the compatibility of IMT and part-time farming. Part-time farming is no problem as such, but appears unfavorable for collective action, which will be necessary to face the future challenges. It is currently fuelled by several factors. First, there is the trend of diversifying income within the actual population of the irrigation scheme. While there is certainly a pull-factor due to burgeoning economic opportunities in the area of the Office du Niger, there are also push-factors, related to bottlenecks in financing, input supply and technical assistance, which limit profitability of rice farming. Next, the lack of fully-fledged property rights on land in the irrigation scheme further drives farmers to alternative economic activities for investment. Indeed, some farmers currently feel insecure about whether they will be able to reap the benefits of investments in their rice plot in the long term. In order to keep the current setting of water management workable, there might be a need of agricultural policy supporting rice farming. Second, the disproportional inflow of part-time farmers through new plot allocations speeds up the increase of their numbers. All land in the vicinity of the Office du Niger belongs to the Malian state, and the expansion of the irrigated surface is financed by public funds. In principle, every citizen should thus have access to irrigated land. Yet, to enhance the prospects for successful farmers' water management, preferential access for full-time farmers might be justified.

Box 10 Land and water rights

At first sight, land and water rights appear rather insecure in the Office du Niger irrigation scheme. Actual practice however turns out much more rosy. Land rights depend on the type of contract. Farming contracts, a first type, are yearly and tacitly renewable on the condition that the farmers' obligations are fulfilled (payment of the water fee, conservation measures, etc.). The second type, farming licenses, have an indeterminate duration and are transferable to heirs. Farmers can obtain them after two years of cultivation with due diligence. Eviction is still possible when the farmers' obligations are violated. The vast majority of farmers however still have farming contracts, either because they are unaware of the other type or because they cannot tell the difference. In practice, the farming contracts are also of an indeterminate duration, as farmers have never been evicted but for failure to pay the water fee. They are also transferable to heirs, who can even ask to subdivide the plot, which is called "séparation de famille". Actual rights go even much further. Indeed, even though illegal as farmers do not own the land, transactions occur frequently enough for prices for renting and selling land to be well established and known to everybody. The practice seems furthermore to be tolerated by the central management.

Water rights are not stipulated explicitly, but the ongoing practice is that water delivery is on demand and the central management guarantees water deliveries on all official plots.

In-depth interviews with village leaders reveal how land and water rights are perceived by farmers. Several points stand out:

- In irrigated agriculture, land and water rights are logically inseparable in the view of farmers, since you cannot use one without the other. This implies that the water fee is paid for both the land and the water at once. Paying the fee gives you access to irrigated land, i.e. a plot to which water is delivered.
- Since land and water have to be paid for, they do not belong to the farmers; they belong to the state, embodied by the central management of the Office du Niger.
- Perpetual use of land and unlimited quantities of water are guaranteed, on the sole condition that the water fee is paid. On the other hand, eviction follows immediately and irrevocably the first time the water fee is not paid, irrespective of how many years it was paid on time (even though you can try to get another plot using a made-up name). Once you are evicted, you have lost all your rights, and no compensation is paid. This is considered unjust.

Even though established farmers have far-reaching land and water rights, access to these rights for outsiders to the irrigation scheme is highly unequal and unfavorable for the poor. Indeed, plots are allocated increasingly to non-farmers. Staff members of the central management appear to be first in line, as are local researchers, traders, civil servants etc. This practice violates one of the major objectives of the Office du Niger, which is reducing rural poverty. From the point of view of the non-farmer beneficiaries, it makes however complete sense. As a staff member of the central management articulated: "It would be absurd: you work at the Office du Niger and you buy your rice at the market?"

PART III

TOOLS FOR PARTICIPATORY WATER MANAGEMENT

Summary

This dissertation states that farmers need appropriate training and support to help them in their management tasks. Using the results from the field study on the impact of management practices on performance (Part I) and the analysis of the social forces behind water management (Part II), this part presents two types of tools that support farmers' water management. The first tool consists in training material on the principles and processes of water management. It contains extension posters and a manual for trainers. The posters show how individual management practices and collective action affect irrigation efficiency and result in or alleviate irrigation and drainage problems. Given the difficult social context and the many practical constraints that farmers face, it would be unrealistic to optimize all aspects of water management. Still, some action must be taken to increase irrigation efficiency, which is urgently required when the irrigated area expands and water becomes more scarce. Therefore, the second tool is a simulation model of water management. This model is an analytical tool, which helps the user to find the best mix of practices that increase irrigation efficiency to a desired level while preserving farmers' interests. The results of the simulations are subsequently translated into guidelines. Both tools have been presented in a workshop uniting farmers, extension officers, the presidency of the central management and international donors involved in the irrigation scheme. The positive reactions confirmed the necessity of training and training material on water management and validated the approach for their development.

Chapter 9

Didactic tools for supporting farmers' water management in collective irrigation schemes

Abstract[1]

In many irrigation schemes, Water Users Associations (WUAs) acquired the responsibility over water management after withdrawal of the state. Based on the success of some indigenous irrigation schemes, it was assumed that farmers could become easily managers. As decision-making was the exclusive terrain of the governmental agencies that ran the schemes, farmers never gained the necessary experience with water management. Therefore, training of farmers and WUAs on the principles and processes of water management is essential. This chapter reports on the process of developing training material on water management for a case study in the Office du Niger irrigation scheme. This process includes (i) setting the training agenda, (ii) selecting and adapting information to be featured, (ii) targeting the audience and (iv) designing the actual training material. It is based on a comprehension of the practical and socio-economic constraints that shape water management and its potential for improvement. A first validation of the approach and examples of the actual training material were obtained in a workshop uniting all stakeholders.

9.1 Introduction

Because of Irrigation Management Transfer (IMT), farmers and their Water Users Associations (WUAs) are taking over management in irrigation schemes all over the world.

[1] This chapter is adapted from: Vandersypen, K., Keita, A.C.T., Lidon, B., Raes, D., Jamin, J.-Y. (Submitted) Didactic tools for supporting participatory water management in collective irrigation schemes. Irrigation and Drainage Systems

Training is essential to prepare them for this task, but is often limited to financial and administrative aspects, such as the structuring of WUAs, conducting meetings, keeping records and accounting. Water management is usually not part of the training package, while in many small-scale schemes or at the lower canal levels, farmers are in charge of it since IMT. Understanding of water management principles and processes is nevertheless a precondition for farmers to become successful managers, but training on the subject is omitted because of the implicit assumption that local knowledge, gained through daily experience, is adequate. Farmers in government-funded irrigation schemes however commonly originate from rain fed agriculture and did not bring a culture of hydraulics with them. Next, upon arrival in the irrigation scheme, a governmental agency monopolized all decision-making on water management so that farmers have even no experience to rely on when IMT was carried out (Shah *et al.*, 2002; Meinzen-Dick *et al.*, 2002). Actually, a lack of training undermines the effectiveness of WUAs throughout the world.

This lack of training is obviously not the only obstacle for WUAs. They must be well designed and accepted by farmers. Furthermore, the right incentives should be in place and the necessary social capital should be available (Ostrom, 1994b; Snellen *et al.*, 2004). A better understanding of water management principles and processes might partly alleviate these other obstacles and as such plays an important role in making WUAs functional. For example, awareness of the available management options and their impact increases farmers' actual control over the system, which might foster their motivation. Furthermore, training can serve as an equalizer, putting every participant at the same level of information. This should in turn favor participatory processes and enhance the potential for cooperation.

The Office du Niger irrigation scheme presents a clear case for the need for training on water management. Irrigation management transfer (IMT), which gave farmers the responsibility over water management at tertiary level, has not lived up to the expectations of the central management. The latter fears that low irrigation efficiencies, insufficient maintenance, drainage problems and conflicts among farmers might jeopardize the ambitious goals of expansion of the irrigation scheme. Currently, WUAs are installed in the irrigation scheme to help farmers organize water management in order to improve its performance (Chapter 7). Up to now, training is however limited to explaining the organization and administration of WUAs and farmers' responsibilities on water management. Farmers appreciate their independence, but lack the necessary knowledge and skills to be in full control of water management (Colin and Petit, 2007). The training agenda will therefore have to include principles and processes of water management.

Office du Niger staff is in charge of the installation and training of WUAs. For this purpose, it disposes of an extension service in each of the administrative zones. However, the extension service does not contain sufficient staff to be in close contact with farmers. Water guards on the other hand, who operate intakes and control structures of secondary canals, interact daily with farmers and in practice do most of the extension work. In the remainder of the chapter, the term extension officer is used to mean both the actual extension officers and water guards who assume that role. Most extension officers have had no technical schooling and despite their job are not well up in water management. To increase their capabilities in extension, they need training themselves. During several preliminary workshops, extension officers furthermore expressed a demand for didactic material to use during training sessions. The central management acknowledged the need for training and training material on water management for WUAs and extension officers. Consequently, they requested a translation of the knowledge acquired during the research project into training material. This chapter reports on the development of the training material, which consists of extension posters to be used by extension officers during training sessions, and a trainers' manual, for the extension officers themselves.

9.2 Approach

Over the past few decades, research and development for extension has advanced substantially in domains such as agronomy, integrated pest management and soil conservation, with new methodologies being developed and tested (Norton *et al.*, 1999; Marra *et al.*, 2003; Bodnár *et al.*, 2006). Training and extension has evolved from a model of 'transfer of technology' to more participatory approaches (Vanclay and Lawrence, 1994; FAO, 2001; Bodnár *et al.*, 2006). In the first model, scientists identified problems and developed solutions, which were then transferred by extension officers. This approach suffered from a lack of adoption, as scientists neglected cultural, socio-economic or practical constraints and ignored farmer-developed solutions already in place. Rather than proposing a particular solution, participatory training aims to develop farmers' problem solving ability by making knowledge available and stimulating the decision-making process (Stemerding *et al.*, 2002; German, 2006). As such, the content of training package consists in principles, methods and possibly some examples of solutions from which farmers can select (FAO, 2001; Loevinsohn *et al.*, 2002). These solutions can take into account current farmers' practices or existing local knowledge (Defoer *et al.*, 2002). The training material will have to be used in the specific context of the target area, which very often implies some constraints. They can be physical, agronomic, economic, socio-cultural and institutional. These constraints determine which variables in the relations under study should be considered as fixed, and which can be adjusted. Researchers' role has thus shifted from developing innovations to making information available that takes into account local practices and constraints. Farmers and extension officers participate in this process by giving feedback on the identification of problems and the information developed (van de Fliert and Braun, 2002).

Not all farmers need to be trained directly by extension officers, as useful knowledge is easily diffused. This diffusion process can however be stimulated by including opinion leaders in the training sessions, as they are key for information transfer among their peer (Feder and Savastano, 2006). These patterns of information transfer might however exclude particular groups of society, which consequently have to be targeted explicitly. A good knowledge on the social environment is therefore necessary.

On the basis of these principles, an approach is elaborated for the development of training material that consists of five steps.

1. Setting the training agenda using the insights of a stakeholder analysis;
2. Selecting which parameters should be considered as variable and which as fixed, through an investigation of the physical, agronomic, economic, socio-cultural and institutional constraints that shape water management and its potential for improvement;
3. Targeting the audience of extension officers through an analysis of the patterns of transfer of information on water management;
4. Designing the actual training material;
5. Presenting the training material to local stakeholders in order to validate the approach and obtain feedback.

Depending on the outcome of the last step, one or more of the previous steps can be reiterated, after which step five is repeated.

9.3 Results

9.3.1 Setting the training agenda

Results from the stakeholder analysis show that the central management prioritizes increasing irrigation efficiency to make the expansion of the irrigation scheme possible. Farmers on the other hand do not care about efficiency, but value easy irrigation and drainage highly. Indeed, easy irrigation and drainage implies a minimal labor input, which is important as it comes at the cost of time available for other income generating activities or leisure. Furthermore, when severe, irrigation and drainage problems might affect quality and quantity of rice yields. Low irrigation efficiencies are, besides a structural shortage of drainage capacity, an important cause of recurring drainage problems. Unfortunately, individual farmers' efforts to improve efficiency dissipate over a large area and only combined efforts would have a tangible impact. Many farmers are furthermore not aware of the effect of water losses on drainage problems. Current water management strategies imply a systematic over-supply of water, which imply low irrigation efficiency, but allow easy irrigation without the need for collective action on water allocation. Only after a supply crisis or in tertiary blocks with an unfavorable topography, collective action on water allocation is required to avoid irrigation problems. Not all tertiary blocks however dispose of the necessary social capital to establish it.

Meanwhile, the expansion of the irrigation scheme is already under way. As the primary canal level imposes a bottleneck on total water deliveries, over-supply at one moment will inevitable be alternated by shortages on other moments. Farmers whose plot has an unfavorable location will be the first to suffer. Furthermore, drainage problems currently affect one third of the surface at harvest. Given the structural shortcomings of the drainage system, the problems cannot be expected to disappear soon.

The following topics are set on the training agenda:

- How individual management practices and collective action affect irrigation efficiency and increase or reduce irrigation and drainage problems.
- What is the link between water losses and drainage problems.
- Which management strategies can be used to cope with irrigation and drainage problems or alleviate their consequences.

9.3.2 Selecting the fixed and variable parameters

Over the past decades, some technical interventions greatly improved the performance of the irrigation scheme. Rehabilitation and modernization of irrigation infrastructure have nearly eradicated irrigation problems. Furthermore, the introduction of rice transplanting reduced water requirements at the onset of the growing season and decreased overall consumption. At present, it is however unlikely that more of such interventions will be implemented. On the other hand, improvements in both individual management practices and collective action are expected to further increase the irrigation scheme's performance. In fact, there exist various management practices which result in quite different performance levels. Therefore, management practices are considered as the variable parameters when developing the training material, while infrastructure and cultural practices are considered fixed. The only exception is the coordination of cropping calendars within a tertiary block, which should be considered as a fixed parameter. Indeed, labor constraints typically occur at the onset of the growing season, since land preparation and transplanting are labor-intensive tasks. Farm households with little family workers need the help of day laborers, which at that moment are in short supply. This forces them to postpone the cropping season. Farm households without their own equipment for land preparation face similar constraints, as they need to rent it from neighboring farmers. In addition, financial constraints can provoke delays, as farmers struggle to purchase necessary inputs, such as sowing seed. On the other hand, farmers with logistic and financial clout face strong incentives to start early in the cropping season. Bringing their rice early on the market, they can benefit from high prices. All these constraints and incentives make coordination of the cropping calendar nearly impossible (Keita, 2003).

Other management practices also face constraints. First, labor is highly valued by farmers. Furthermore, among the cultural practices, such as fertilization and weeding, water management has a low priority (Bastiaens, 2005). Consequently, even though few farmers will encounter hard labor constraints during most of the growing season, proposals that imply an increased labor input for water management might have limited success. On the other hand, current priorities reflect the ample water availability (Bastiaens, 2005). When water becomes scarcer or incentives for rational use are introduced, these priorities might change. Concerning collective action in particular, a strong set of constraint comprises the ineffectiveness of peer pressure, the prevalent egalitarian norms and the absence of customary law regulating resource use in the irrigation scheme. These make it difficult to cooperate or to enforce rules (Chapter 7). Because of these constraints, any training aiming to enforce collective action for water management inevitably loses effectiveness. Certain evolutions or strategies might however alleviate them. First, WUAs can draw up their internal code and provide sanctions to enforce it. On the condition that WUAs are institutionally well designed, this could cancel the problem of rule enforcement. Second, village leaders today often possess a certain authority over water management. Their physical or moral presence at the training and extension sessions might enhance the effectiveness.

There are furthermore several factors on which individual farmers, or even farmer groups at the level of the tertiary block, have little impact. First, the water level in the secondary canal partly determines the incoming flow rate in the tertiary canal, but its regulation is the domain of the central management. Second, water losses in primary, secondary and tertiary canals, in addition to the drainage water from all tertiary blocks, fill the collector drains. The water level in the collector drains directly influences the water level in the tertiary drains, as they are communicating vessels. As such, actions of a single farmer or a single tertiary block are negligible. These factors are therefore considered as fixed.

9.3.3 Targeting the audience for training

The audience for the training corresponds to all persons involved in water management at tertiary block level. Based on the results of the field study, this section formulates several recommendations to target the training to a specific audience. First, training should be targeted to the farmers of tertiary blocks that confront irrigation and/or drainage problems or irrigate with excessively low efficiency. This implies that many tertiary blocks where water management does not follow the prescribed rules, but that still achieve good performance, can be ignored. Such an approach breaks away from the current normative view on how water management should be organized, imposing it indiscriminately on all tertiary blocks. It is however believed that this approach will make training efforts more effective. This is extremely important in an environment with only about a hundred extension officers for more than 30,000 farming families.

Second, the village leadership might have a crucial role to play in the adoption of improved management practices. They furthermore function as opinion leaders in their villages. It is therefore desirable to include them in the target public, either by organizing training sessions especially for them, or by inviting them for the regular training sessions.

Third, as alternative economic opportunities become available in the irrigation scheme, farmers increasingly diversify their income. Many therefore employ seasonal wage laborers to substitute for family labor when the latter have other professional priorities. Furthermore, about 7 % of the land is cultivated by leaseholders. Nevertheless, only plot holders are invited to meetings on water management. It has however been observed that information does not trickle down to wage laborers and leaseholders, as they have no part in traditional patterns of information transfer. Since they are more in need for training than plot holders, they should be explicitly included in the audience.

In the trainers' manual accompanying the training material, a procedure for organizing training sessions is presented. This procedure incorporates the above recommendations and consists of five steps:

1. At the initiative of either farmers or the extension officer, one or more problems are acknowledged, from which a demand for training can result. As most of the extension officers live in the farmers' villages, they are well informed about possible water management problems inside a tertiary block and should therefore be allowed to take the initiative for training.
2. A meeting of the WUA is convoked according to the procedures of its internal code. Starting from this stage, village leaders can be implied in the training process.
3. The meeting aims to establish a consensus on the problem(s) observed and on who is involved.
4. If some of the involved parties (e.g. wage laborers and leaseholders) are not present at the first meeting, it can be decided to convoke a second meeting to which they will be invited. The second meeting again aims to establish a consensus on the observed problem(s).
5. In a last step, the actual training takes place in which all involved parties participate. The extension officer animates a discussion in which a solution to the problem(s) is explored. At this stage, the extension posters can offer some structure to the training sessions and provide the audience with practical and technical information.

9.3.4 Designing the training material

The actual design of the extension posters and the trainers' manual is carried out by a local research center. As part of this research, technical assistance was provided to the research center to supply the scientific input and assist the editing of the manual and designing of the posters. The design phase is however not yet completed. Only one evaluation has been done so far (see below) and further testing and amending the material remains to be done.

The extension posters consist of three modules with each six or seven posters featuring images, tables, graphs and short statements. A first module discusses irrigation and drainage problems viewed from the angle of the cropping calendar. Farmers as well as the central management often attribute problems to the diversity of farmers' cropping calendars at tertiary block level. For the reasons stated above, the module will not recommend an ideal cropping calendar, but rather presents solutions to problems that might ensue from starting too late or too early, and being too dispersed or too much in line. Given their importance in the irrigation scheme, the second module digs deeper into the subject of drainage problems at harvest. It aims to give advice and practical information for different degrees of drainage problems, such as cleaning the tertiary drain when evacuation of water by the collector drain is possible, to the number of days necessary to evaporate a water layer from the rice basins when it is impossible to drain them. The module contains one poster that demonstrates the relation between excessive water use by farmers and the saturation of the collector drains. The third module discusses good irrigation practices at field and tertiary level. It shows farmers how irrigation efficiency can be increased through careful field management and by coordinating the opening of the tertiary intake. Furthermore, whereas module one only introduces the notion of coordinating water allocation in periods of high aggregate demand, module three presents some practical allocation schemes applicable in different situations (Figure 9.1).

The trainers' manual aims to boost the capacity of the trainers on water management issues. A first part treats the basics of hydraulics, crop water requirement and performance measurement at an elementary level. During the many interactions with extension officers and water guards, it was observed that not all comprehend such notions as flow rate or slope of the hydraulic surface in a canal. As these concepts are used in training sessions, it is indispensable for trainers to grasp them profoundly, as it will be their role to explain them to farmers. The second part explains the principles of the targeting of the training sessions and describes the procedure for organizing training sessions (see section 9.3.3). The third part of the training manual contains background information and instructions for use of the extension posters.

9.3.5 Presenting the training material to local stakeholders

A one-day workshop was organized to present for the first time the training material to farmers, extension officers, the presidency of the central management and international donors involved in the irrigation scheme. First, the approach to the development of the training material was explained and the extension posters and trainers' manual were shown. Next, discussions among the participants were animated.

Farmers reasserted the need for training on water management and confirmed their view that it is a necessary condition for WUAs to become functional. Likewise, extension officers emphasized that their capabilities as trainers need to be reinforced, both concerning the technicalities of water management and the organization of training sessions. Consequently, farmers and extension officers welcomed the initiative to provide training material and validated the approach for its development. Thereupon, the presidency of the central management and international donors recognized the importance of completing the design of the training material and expressed their willingness to cooperate for the organization and financing of extension programs. These will include a 'training of trainers' to increase the capabilities of extension officers, and farmer training.

Figure 9.1 Example of an extension poster

During the discussions, some questions, remarks and suggestions were raised concerning the topics of the training material and particular terms or phrases. Furthermore, the importance of translating the extension posters in Bambara, the local language, was stressed. In a next step, working groups will be formed including farmers and extension officers to propose practical improvements for the training material. Then, the design phase will be resumed.

9.4 Conclusions

After IMT, the training of farmers and WUAs concerning water management is often neglected. A good understanding of water management principles and processes is nonetheless one of the conditions for a successful management transfer. In this chapter, an approach for developing training material on water management is presented and illustrated for the case of the Office du Niger irrigation scheme. The first step in the approach is defining the objectives of training, which builds on a stakeholder analysis of water management. Second, the training material is selected. At this point, practical and socio-economic constraints of water management determine which variables in the relations under study should be considered as fixed, and which should be presented as adjustable. Third, based on knowledge of the social environment, the audience of the training is targeted in order to make training more effective. A last step is the design of training material. In the scope of this research, examples of extension posters and a trainers' manual were designed and presented in a workshop to farmers, extension officers, the presidency of the central management and international donors. The positive reactions confirmed the necessity of training and training material on water management and validated the approach for their development. During the workshop, the stakeholders agreed to organize an extension program in which the training material will be used.

The different steps in the approach result from research on the practical and socio-economic constraints that shape water management and its potential for improvement and the impact of management practices on performance. This demonstrates the role research can play in providing input for training.

Box 11 Participatory construction of irrigation infrastructure

In view of the large agronomic potential and demographic pressure on irrigated land, the Malian government pursues a fast expansion of the Office du Niger irrigation scheme. However, the availability of funds to finance new infrastructure restrains the growth rate. Therefore, a new approach is experimented in which the beneficiaries of new irrigation infrastructure participate in the construction process to reduce its cost. State or donor financed professional firms still dig the primary and secondary canals and construct the intake of the tertiary canals. Then, farmers take over and dig the tertiary and field canals, install the field canal intakes and outlets, clear the land from its original vegetation, level it and divide it into rice basins. The approach was first implemented in the late 1990s, and even though a full appraisal might be premature, some preliminary evaluations have been made (Diassana and Sidibé, 2002; GEDUR, 2003). The first few growing seasons, yields disappointingly averaged 2 t/ha. In general, beneficiaries received plots of less than a hectare per farming family, which is much too small for sustaining a livelihood. Consequently, farmers had to combine different sources of income, and the allocation of production factors was not always optimal for their rice farm. Furthermore, for farmers originating from the rain fed area surrounding the irrigation scheme and new to rice farming, access to credit, availability of equipment and know-how on cultural practices of rice farming were often insufficient. Even though they hoped that obtaining a rice plot would entail an escape from poverty, many ran into financial deficits, were unable to pay the water fee and eventually were evicted from their plot without compensation (Dave, 2004). Consequently, their initial investment was lost.

Apart from the disappointing yields, the issue of water use raises some questions. Four out of the 36 tertiary blocks from the sample described in Chapter 5 were constructed with the participatory approach. Their efficiency (barely 25 %) is among the lowest of the sample. Even though many factors, such as soil conditions and water management practices, contribute to explain this figure, the banks of the tertiary canals, constructed by farmers in 2002, were very feeble and frequently breached, provoking huge water losses (Vandersypen *et al.*, 2005). Even though one should be careful to generalize findings from such a small number of cases, the poor physical condition of tertiary infrastructure is a general feature where farmers participated in the construction process (Diassana and Sidibé, 2002; GEDUR, 2003). One possible explanation is that farmers did not learn from the professional firms as intended. Indeed, whereas they were supposed to be working in parallel, delays in timing of the firms made that farmers often started before they arrived. Another explanation, as one farmer stated, is that “men simply cannot replace machines”.

While it has been shown that farmers are prepared to participate in the construction of irrigation hardware when convinced of the benefits, the participatory approach might need some qualification. Firstly, technical and managerial assistance is a must during both the construction phase and the first years of cultivation to ensure the sustainability (financially and in terms of water use) of the investment. Secondly, land rights need to be adjusted so that farmers who leave their plot (voluntarily or not), are compensated for their investment.

Chapter 10

Adapting irrigation strategies to water scarcity: A modeling approach

Abstract[1]

Collective irrigation schemes throughout the world are facing pressure to increase irrigation efficiency, which relies heavily on improved farmers' water management. Farmers however face a variety of constraints that get in the way of optimal management practices. This chapter presents a modeling approach to find the best mix of practices to increase irrigation efficiency while preserving farmers' interests. This approach combines an understanding of the physical and of the social constraints in the irrigation scheme. As such, not only the dynamics of the physical resource can be modeled, but also farmers' management practices and decision rules that interact with this resource.

10.1 Introduction

The challenge of irrigation is to produce enough food for the growing population, while water is becoming increasingly scarce (Howell, 2001). Following the global trend of transfer of the management of natural resources to the users, farmers now participate in decision-making in most irrigation schemes. Consequently, they will have to formulate strategic answers to face this challenge. However, having limited experience with water management, they are not necessarily well prepared for this task and might need decision support. In particular, they need to understand which are the alternative management options available to them and what are their consequences.

[1] This chapter is adapted from: Vandersypen, K., Raes, D., and Jamin, J.-Y. (Submitted). Adapting irrigation strategies to water scarcity: A modeling approach. Journal of Irrigation and Drainage Engineering.

The Office du Niger irrigation scheme reflects these challenges quite well. Rehabilitation of the irrigation infrastructure started in the 1980s and solved technical bottlenecks limiting good performance (Chapter 3). Still, low irrigation efficiency results in recurring drainage problems at harvest, which incur increased production costs as well as a reduction in the quantity and quality of yields (Chapter 6). The irrigated surface is however expanding rapidly, and in the coming 20 years, the 80,000 hectares already in use will be doubled or even tripled. The water resource, currently abundant, will thus inevitably become scarce, which might result in irrigation problems. The largest potential for increasing irrigation efficiency exists at the tertiary level, where farmers are responsible for water management after the institutional reforms (Ouvry and Marlet, 1999). As farmers already in place have no stake in the expansion of the irrigation scheme, they are not necessarily interested in investing time and effort in improved water management to increase irrigation efficiency. In addition, water and the irrigation infrastructure are common resources. Hence, many aspects of water management need to be tackled collectively, whereas the social context complicates collective action. Finally, farm management poses some constraints on farmers' liberty of action. In summary, it can be stated that although optimizing water management is not always feasible, actions must be taken to increase irrigation efficiency (Chapter 3 and Chapter 7).

Even though the practical setting may vary, this problem is common to irrigation schemes throughout the world and revolves around the following question: Which management practices succeed in improving irrigation efficiency while avoiding irrigation problems? This question often concerns complex and interrelated relationships. Furthermore, future scenarios might be completely different from today's (e.g. with water scarcity replacing abundance). A simulation model of water management can therefore provide an appropriate analytical tool to formulate guidelines for improving water management (Olsson and Andersson, 2007). However, such a model should not only represent the dynamics of a physical resource, but also farmers' management practices and decision rules that interact with this resource (Feuilette *et al.*, 2003). It therefore has to build on knowledge of both a physical and a social system. In this chapter, a simulation model is presented that is able to simulate the impact on performance for different combinations of management practices and for different conditions (e.g. water availability, weather conditions, etc) and as such to provide an answer to the question raised. This model is specific to the Office du Niger irrigation scheme. However, as many irrigation schemes face similar challenges, the approach is relevant for other situations.

10.2 Materials and methods

10.2.1 Data collection

The simulation model is designed conceptually using the results of a field study that lasted three years (2003-2005). The field study included an analysis of organization and performance of water management on a sample of 36 tertiary blocks (Chapter 5). Management practices and field conditions are described in the literature (e.g. Kamissoko, 1999; Condom, 2000; Klinkenberg, 2000; Boeckx, 2004; Dicko, 2005) and validated through interviews with farmers and regular field observations. To this end, water management strategies were discussed with 8 farmers in semi-structured interviews (see Appendix 3). Furthermore, irrigation activities on 12 of the 36 tertiary blocks were monitored closely throughout the day for several periods of one week.

10.2.2 Model framework

The simulation model is an expert system in the sense that it incorporates farmers' decision rules in a series of "if-then"-relations that determine water flows. Not all decision rules are deterministic, meaning that every event has only one outcome. Therefore, some probabilistic functions are included, making the model stochastic.

The model simulates the water level in the tertiary canal and the water stored in a selected management unit in the course of time, based on a water balance which considers the incoming and outgoing fluxes. Water levels, amount of water stored and fluxes can be translated in performance indicators assessing irrigation efficiency, irrigation problems and crop water stress (output). The input consists of farmers' management practices and external factors (Figure 10.1). A specific combination of input data constitutes a scenario.

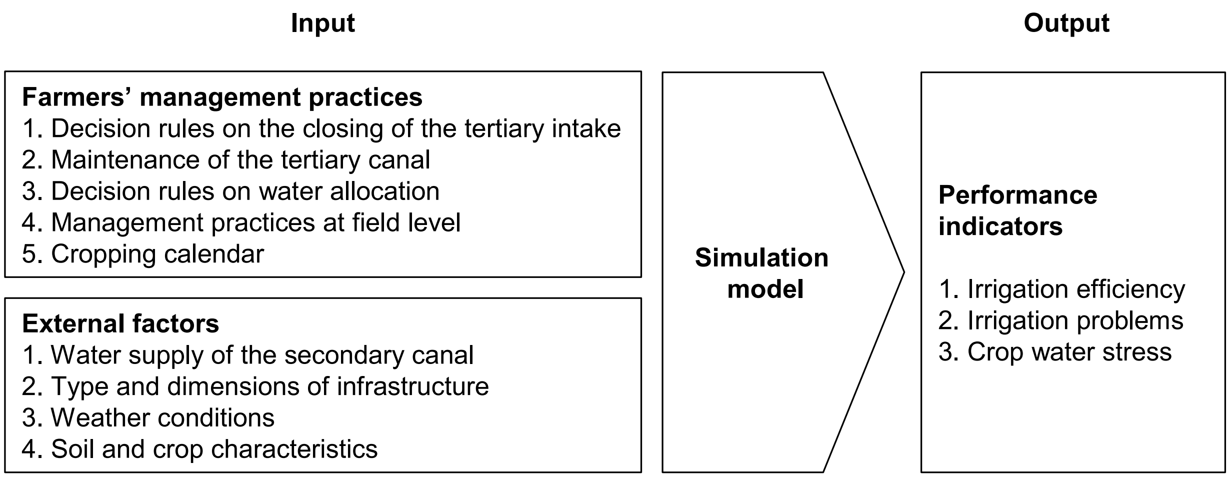


Figure 10.1 Input and output of the simulation model

Water level in the tertiary canal

The tertiary canal is represented as a cascade of reservoirs, each corresponding to a section of the canal in-between two nodes (Figure 10.2). At each node, a field canal branches off. The water level ($H_{i,t}$) at a particular moment (t) and in a particular section (i) is determined by adding to the water level of a previous moment, the flows in and out the section during the interval (Figure 10.3). The model proceeds with time steps of one second. Within each section, the water level is assumed to be horizontal. It has a fixed length (X) but as canals in the Office du Niger have a trapezoidal cross section, the width of the water surface (B) varies as a function of the water level. Water enters in the first section through the tertiary intake. The flow rate ($Q_{in,1}$) is a function of the water availability at secondary level, the type and dimensions of the intake and the opening of the valve, which depends on farmers' decision rules. The water flow to the next section is determined by the difference in water level of the two sections and calculated using the Manning-Strickler formula and by taking into account the maintenance level of the tertiary canal (Smout *et al.*, 1997). The water level in each section determines the direction of the water flow (in or out of the section). The flow entering a section i ($Q_{in,i}$) equals the flow leaving the upstream section. This cascade continues until the final section is reached, where water can only flow out by returning to the previous section. Furthermore, in each of the sections, water can discharge into the field canals ($Q_{fc,i}$). At the start of each day, the model determines the number of management units that irrigate using a probabilistic function based on the total irrigation requirements of the tertiary block, field losses and the irrigation dose. The irrigation requirements are calculated following the procedures described in Chapter 3 and depend on the cropping calendar and rainfall. Field losses and the irrigation dose depend on farmers' management practices. Next, an algorithm assigns the irrigation turn to specific management units. Allocation rules can regulate both the number and the location of the management units that withdraw water from the tertiary canal. The rate of discharge into the field canals depends on the water level in the tertiary canal and the dimensions of the field intakes.

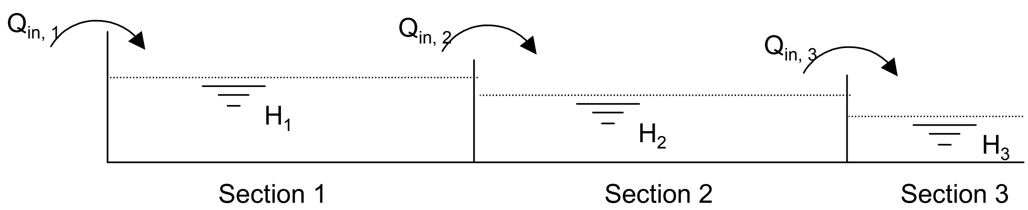


Figure 10.2 Representation of the tertiary canal in the simulation model as cascading reservoirs, with Q_{in} = flow entering or leaving a section and H = the water level in the section

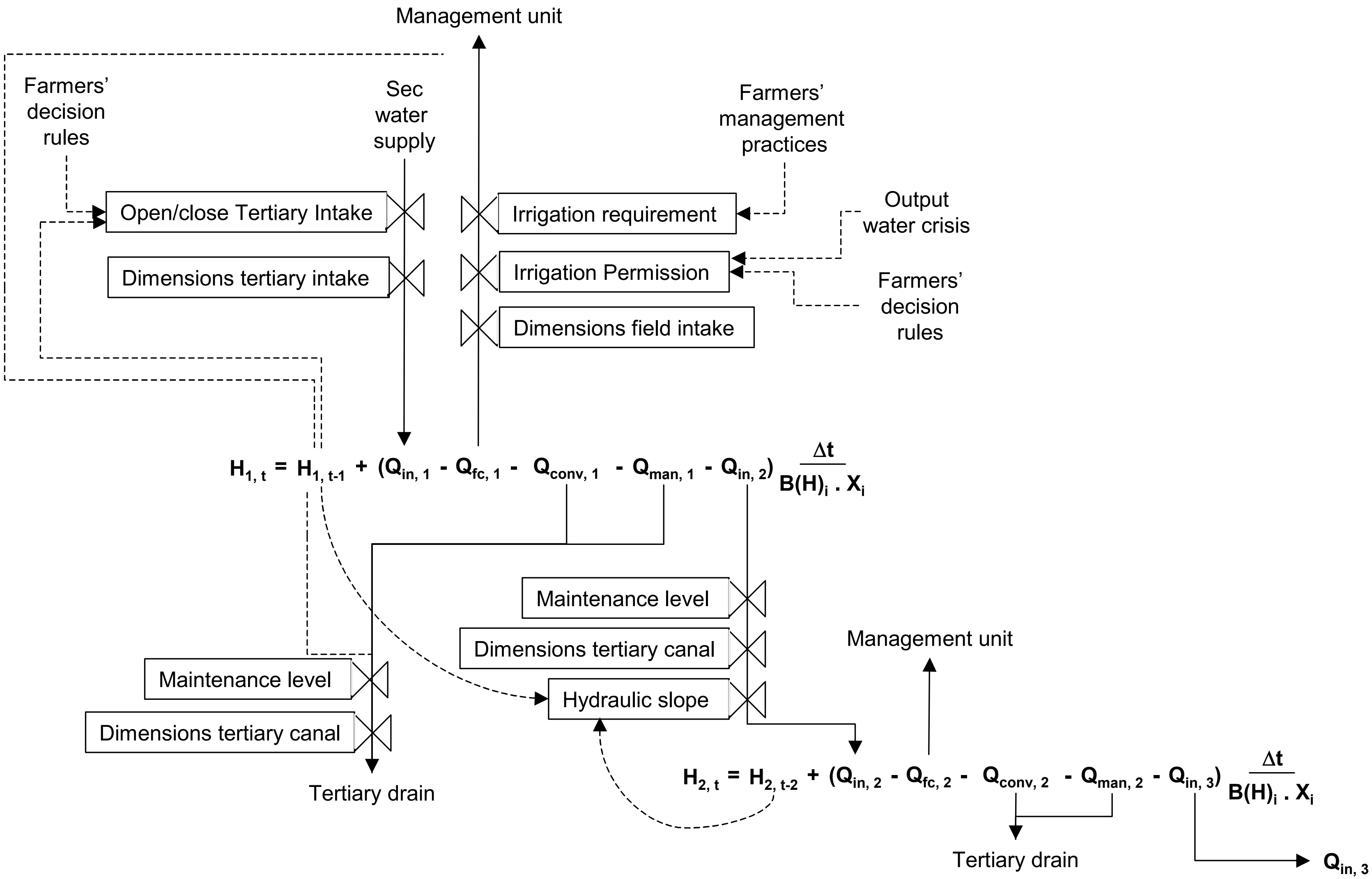


Figure 10.3 Flow chart of ingoing and outgoing fluxes in the sections of the tertiary canal (full line = water flow; dotted line = information flow, H = water level, Q_{in} = flow entering or leaving a section, Q_{fc} = discharge into the field canal, Q_{conv} = conveyance losses, Q_{man} = management losses, Δt = time step, B(H) = width of the water surface, and X = length of the water surface)

Finally, water is lost in the tertiary canal through conveyance ($Q_{conv,i}$) and management losses ($Q_{man,i}$). Conveyance losses are a function of maintenance and the water level. Management losses occur whenever the water level exceeds the level of the overflow structures with the flow rate depending on their dimensions.

The output of the model consists in the total water consumption at the tertiary intake over the period of simulation, which is used as an indicator of efficiency. The number of days that the water level in the tertiary canal drops below 0.3m, 0.2m and 0.1m is calculated as indications of irrigation problems. At 0.3m, irrigation problems might occur for certain management units with an unfavorable topography. At 0.1m, the water level is below the field intakes so that irrigation is no longer possible.

Water storage in a particular management unit

In order to assess the impact of the management of the tertiary canal at field level, the model simulates the water storage (WS) in one selected management unit. Water storage is the amount of water stored in and/or on the soil. It is zero when the soil is saturated, positive when it contains a water layer and negative for an unsaturated soil. The water storage at a certain moment equals the water storage at a previous moment plus the amount of water flowing in or out during the interval (Figure 10.4). Calculations proceed with time steps of one day. Positive (in)flows add water to the management unit and are irrigation (IRRI) and rainfall (P). Capillary rise is negligible on the heavy clay soils of the area (N'Diaye and Guindo, 1998). Negative (out)flows withdraw water from the management unit and are actual evapotranspiration (ETa), deep percolation (DP) and losses (Loss). Lateral drainage occurs at the end of the growing season to evacuate water from the field for harvesting, but is not considered in the scope of this model, which focuses on the periods of irrigation.

The decision to irrigate and the irrigation dose depend on the actual water storage in the management unit compared to a minimum and maximum target level (Figure 10.5). The latter are a function of the growth stage and farmers' management practices, which are adapted according to water availability at the tertiary level. The decision to irrigate is however still subject to possible allocation rules. All rain is supposed to be effective (unless it exceeds the storage capacity of the management unit) and the model retrieves daily rainfall from the input. Actual evapotranspiration is calculated by multiplying reference evapotranspiration with a crop factor and adapted to water stress if the water storage falls below zero following Allen *et al.* (1998). Deep percolation is constant throughout the growing season and as the vast majority of soils have similar physical properties, it is a fixed parameter. Losses are the result of excess irrigation or rainfall. They depend on the physical layout of the management unit and farmers' management practices. Model output consists of the number of days with water storage below 0.1m, 05m and 0m, which are a measure of water stress. Depending on the degree of land leveling, water stress can occur even with positive water storage on parts of the management unit.

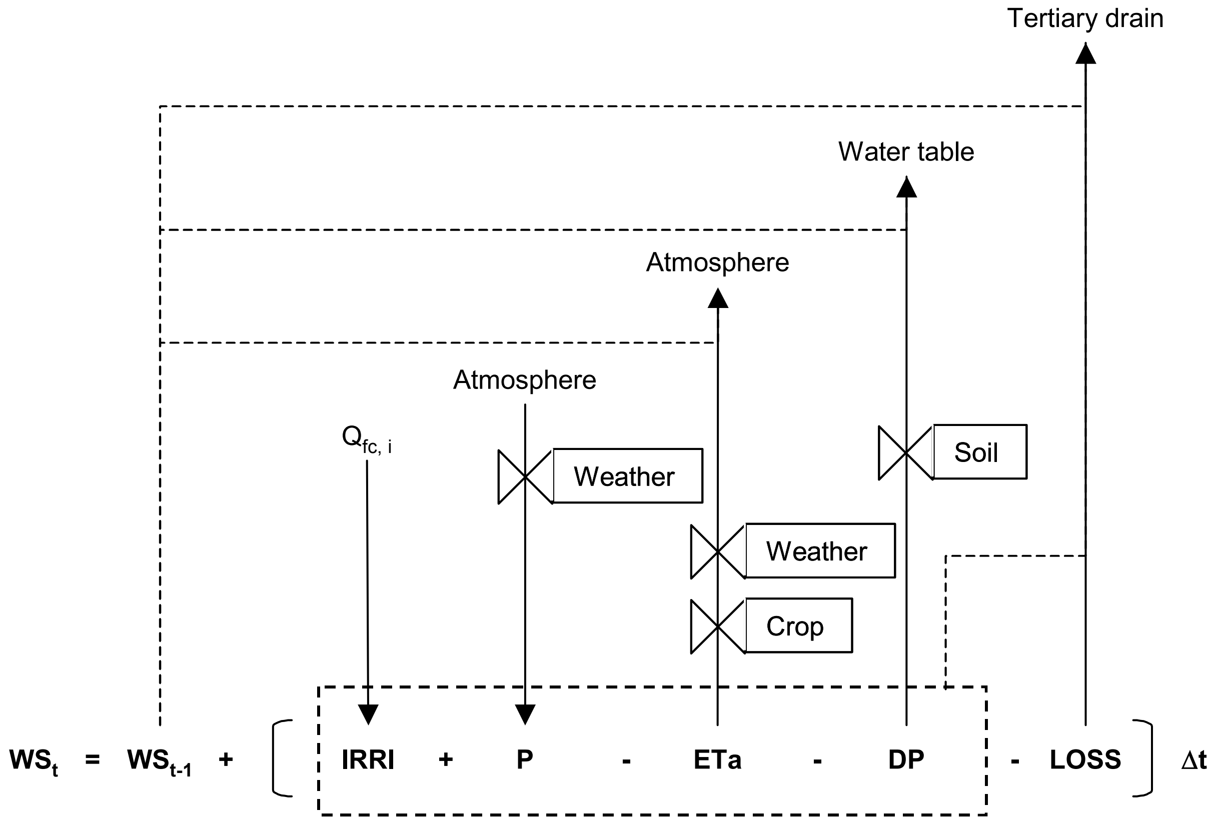


Figure 10.4 Flow chart of incoming and outgoing fluxes of the water balance of the management unit (full line = water flow; dotted line = information flow, WS = water storage, IRRI = irrigation, P = rainfall, ETa = actual evapotranspiration, DP = deep percolation, LOSS = losses and Δt = time step)

10.2.3 Choice of scenarios to be simulated

The simulations study the impact of various interventions on irrigation efficiency and irrigation problems under various external conditions. Three broad issues are singled out on the basis of which scenarios are selected.

(i) *Water saving interventions for a full water supply at secondary level.* Today, average seasonal water delivery to the tertiary blocks lies around 2,000 mm, whereas the target is 1,400 mm (Office du Niger, 2005; Vandersypen *et al.*, 2005). Results from the field study revealed that the over-supply is related to excess delivery to the tertiary block compared to demand, excess application in the fields and field losses (Chapter 3 and Chapter 5). The simulations will evaluate the impact of the following measures:

- Good management practices at field level improve application efficiency and limit field losses by strengthening contour dikes, monitoring irrigation and land leveling.
- A tight control of the tertiary intake, in the sense of decision rules prescribing to systematically close the tertiary intake after irrigation, limit excess delivery to the tertiary block.
- Applying a rotation schedule between field canals makes aggregate water demand more predictable, facilitating adjusting supply to demand.

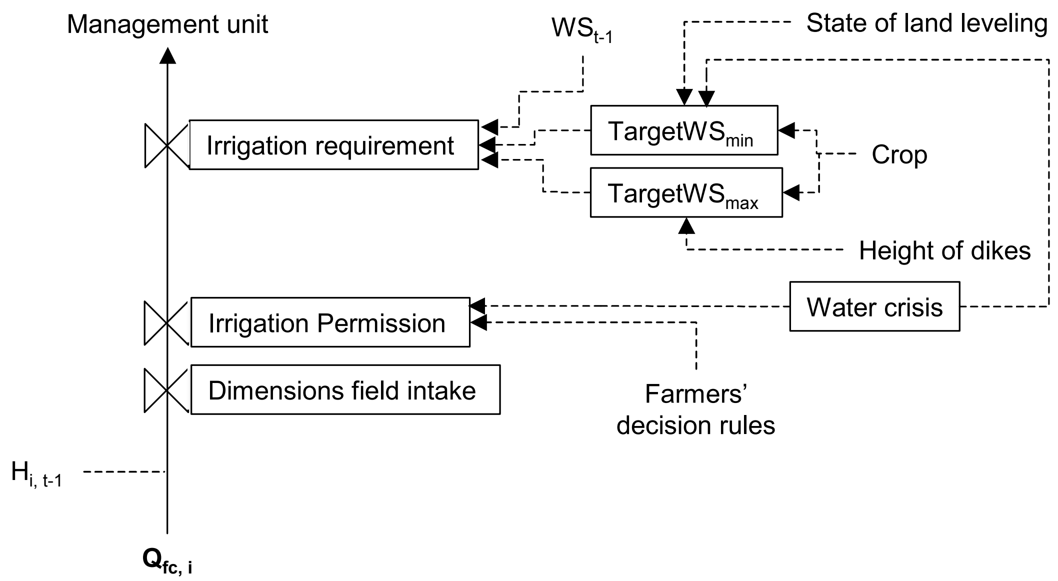


Figure 10.5 Decision model for irrigation of the management unit followed up closely (full line = water flow; dotted line = information flow, boxes represent results from calculations, H = water level in the tertiary canal, WS = water storage in the management unit, Q_{fc} = discharge to the field canal)

(ii) *Water saving interventions for a limited water supply at secondary level.* In a situation where the total water availability is constraint, over-consumption will cause water levels in the secondary canal to drop so that at the tertiary intakes, the nominal flow rate is no longer attained. In addition, at low water levels, fluctuations translate in variations in the incoming flow rate. Therefore, a situation with a relatively low but stable water level is compared to a situation of important fluctuations.

(iii) *Maintenance.* From the field study, it appeared that maintenance does not have a significant impact on efficiency or resulted in irrigation problems under the current circumstances. It will be tested whether these findings still hold when water saving measures are applied and/or the water supply at secondary level is limited.

The simulations were run for various cropping calendars and with rainfall data from three different years, corresponding to a typically dry year (1981), normal year (1990) and wet year (1979). Next, only the most common crop and soil characteristics have been used, which are nevertheless valid for more than three quarters of the surface. Finally, the simulations discussed concern the most frequent physical layout. As such, in the simulations, the tertiary intake is equipped with baffle modules having a maximum capacity of 60 l/s. The canal serves 20 ha through 10 field canals with each a maximum capacity of 20 l/s. About two thirds of the fields are divided into 2 or 3 management units, resulting in a total number of 19 units. Key simulations were repeated for different layouts to test whether the results still hold. This allowed broadening the scope of the guidelines and pointing to important exceptions, but as the analysis is based on the same principles, the results will not be discussed in the scope of this chapter.

10.3 Reliability of the model

As the model is a strong simplification of reality, a validation *sensu strictu* is impossible. In particular, the model input is too simple to replicate observed scenarios exactly. Furthermore, not all performance indicators produced by the model have been measured in the field. However, in order to be reliable, output of scenarios close to those observed in the field should be in line with measured performance indicators (Feuillette, 2003). In addition to the performance indicators, some process indicators can be compared, such as the opening of the intake of the tertiary and field canals.

Scenarios from 3 out of 36 tertiary blocks (named block A, B and C) in the 2004 growing season have been used for the verification. Input data for the model and output and process indicators are based on measurements, observations and calculations. The dimensions of the tertiary intake, tertiary canal, field intakes and management units were measured. For the water supply of the secondary canal, daily records of the water level above the sill of the tertiary intake are used. Based on observed planting and harvesting dates, 10-day irrigation requirements could be calculated. Daily rainfall data were obtained from a nearby weather station. Input concerning management practices is based on interviews and field observations. The simulation period covers July to September, which is the main irrigation period. For those months, water consumption at the intake of the tertiary block was measured using the procedures described in Chapter 3. The occurrence of irrigation problems and water stress were assessed qualitatively in interviews, as described in Chapter 5. Daily records of the opening of the tertiary intake are available for each block. The opening of field canals was observed once every fortnight. Consequently, only a few observations are available for each tertiary block, which cannot be considered representative. In order to obtain a rough idea whether the model simulates the opening of the field canals good enough, observations of all blocks of the sample with 6 to 8 field canals (118 observations) were lumped to compare with simulations for block A and B. Likewise, observations of all blocks with 9 to 13 field canals (89 observation) were lumped for comparison with block C.

Block A counts 8 farmers. They do not coordinate water allocation, even in times of water shortage. The 2004 growing season witnessed several periods of water crisis because of supply disruptions at secondary level. On other occasions, the tertiary intake remained closed for several days because the water guard, detaining the key, was unavailable. These water crises were furthermore prolonged, as when supply restored, all farmers started irrigating at once. Consequently, several of them mentioned irrigation problems. The water guard operating on the corresponding secondary canal is rather strict and frequently closes intakes when he estimates that no one is taking water, and as such helps to limit water consumption. The maintenance level of the tertiary canal was average throughout the 2004 growing season. Transplanting stretches from the end of June to mid-August.

Block B has only three farmers. Coordinating water allocation is rarely needed, as the tertiary block is seldom confronted with water crises. Indeed, in 2004, none of the farmers mentioned irrigation problems. Not much attention is paid to the closing of the tertiary intake, which is often left open even when no one is irrigating. Consequently, water consumption is high. Maintenance of the tertiary canal is carried out every growing season, resulting in an excellent maintenance level. The entire tertiary block was transplanted between the end of June and the end of July.

Block C has 11 farmers. Transplanting extends from mid-June to the end of August, with a peak by the end of June. Maintenance worsens towards the tail end of the tertiary canal and can be considered average overall. Farmers on this block do not cooperate on water management. Whereas blocks A and B have baffle modules at the intake of the tertiary canal, block C has a semi-modular intake. Management at field level is considered bad for all three blocks, since on several field visits, water leaks to the tertiary drain through breaches or overflow have been observed. As a rule, farmers are not present during irrigation.

Table 10.1 shows the simulated and observed performance and process indicators of the scenarios for the three selected tertiary blocks. Simulated total water consumption and the occurrence of irrigation problems and water stress are in line with observations. The opening of the tertiary intake is simulated rather well, except for block A. This is however due to the fact that in this block, the intake was closed with a padlock by the water guard several times despites farmers' water requirements. This was modeled by setting the water supply at secondary level at zero for those periods. As there was an unfulfilled water demand, the model however sets the opening of the intake at maximum all that time.

Table 10.1 Comparison of simulation results with observations for three different tertiary blocks.

Indicators	Block A		Block B		Block C	
	Sim	Obs	Sim	Obs	Sim	Obs
Performance indicators						
Total water consumption (mm)	807-951	824	1,293-1,522	1460	946-1,099	999
Irrigation problems (# of days with water level < 0.3 m)	37-44	Yes	0	No	16-28	Yes
Water stress (# of days with water storage < 0.15 m)	0-5	No	0-0	No	0-0	No
Process indicators						
Probability of field intakes to be in operation at the same time at the number of						
0	45%	26%	25%	26%	23%	20%
1	23%	19%	50%	19%	35%	15%
2	13%	19%	17%	19%	17%	24%
3 - 5	13%	34%	8%	34%	15%	35%
> 5	6%	1%	0%	1%	9%	7%
Probability of the tertiary intake to be						
Closed	24%	40%	21%	19%	40%	56%
Open between zero and maximum width	17%	51%	43%	49%	-	-
Open at maximum width	59%	9%	36%	32%	60%	44%

Regarding the number of field canals in operation, there is some divergence between simulated and observed results. Indeed, the simulation model underestimates the number of open field canals. This is due to the simplifications of the model compared with reality. First, in practice, some fields lie on a slight elevation. Consequently, irrigation will advance slowly and to reach a particular dose, more application time is required. In the model, all field canals can irrigate at their design flow rate when the water level in the tertiary canal is high enough. Next, farmers sometimes forget to close the field canal after irrigation, and some have been noted to remain open for days. Such negligence is very arbitrary and the model does not consider it. For block A, there was furthermore an overestimation of high numbers of open field canal. This distortion once again results from the closing of the tertiary intake. In the model, an unfulfilled water demand that last several days translates in field canals that remain open all that time. As in practice, the tertiary intake was closed, farmers closed their field intakes of fear that water would actually flow back to the canal, which is impossible in the model. Overall, it can be concluded that the model is a fair enough representation of reality to be suitable as an analytical tool.

10.4 Results and discussion

Figure 10.6 shows the impact of different measures on total water consumption in a normal rainfall year and for the most frequent cropping calendar. Simulations cover the months of July to September, which account for about 75 % of seasonal water requirements and delivery. When applied as a single intervention, the rotation schedule is most effective in reducing consumption, followed by a tight control of the tertiary intake and good field management practices. None of the measures individually however succeeds in remaining below the target consumption, which for the three months of the simulation corresponds to 1,050 mm. From the simulations, it appears that combining good management practices with either a rotation schedule or a tight control of the tertiary intake does reach that objective. On the other hand, a tight control of the tertiary intake does not add much to the advantages of a rotation schedule. Indeed, both help to adjust water delivery to the tertiary block to demand.

As a single intervention or in combination with good field management, the rotation schedule is clearly more successful than a tight control of the tertiary intake. Nowadays, farmers seldom apply a schedule as it severely constraints their flexibility and requires heavy monitoring and sanctioning to make farmers respect it. Only in case of water crisis, a schedule is applied, and even then, not all groups of farmers succeed in surmounting free-rider problems (Chapter 4). In contrast, a tight control of the tertiary intake does not demand a radical change in farmers' actual habits and shirking by one farmer does not punish the others. It is sufficient that after irrigating, they check on other irrigation activities in their tertiary block before going home at night. This way, they can prevent over-supply, which usually occurs when the intake remains open all night while no one irrigates. Not even all farmers need to contribute equally. Another option is that one of the farmers is made responsible for checking on irrigation activities at the end of each day and closing the tertiary intake if necessary. Both the rotation schedule and a tight control of the tertiary intake require cooperation between farmers. Management practices at field level are an individual matter, and therefore perhaps easier to implement. On the other hand, they are subject to the same incentives of free-riding and moreover harder to monitor. Nevertheless, they seem a necessary ingredient to achieve the target for water delivery. With water supply at secondary level at full capacity, irrigation problems never occur, regardless the measures to reduce consumption. These results are analogous for different cropping calendars and in dry or wet years.

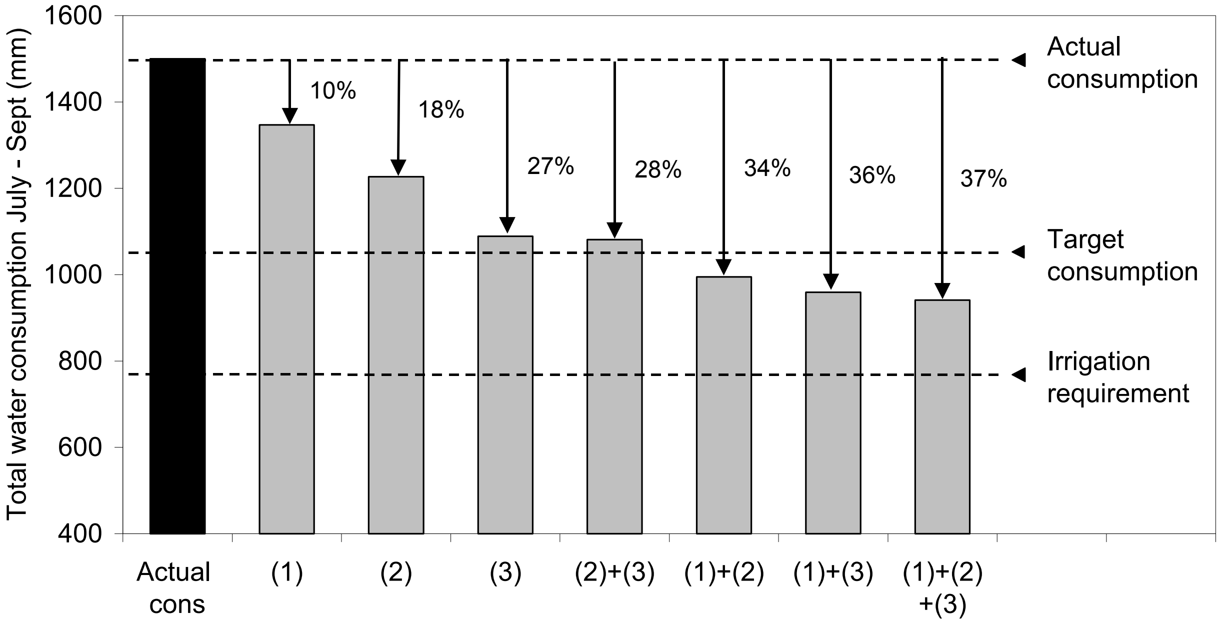


Figure 10.6 Impact of different measures on total water consumption in a normal rainfall year and for the most frequent cropping calendar (transplanting evenly spread between mid-June and mid-August and harvesting starting in October)
(1) Good management practices at field level
(2) Tight control of the tertiary intake
(3) Rotation schedule for water allocation

The situation becomes completely different when the water level in the secondary canal drops. When water allocation among field canals is unregulated, chances become real that demand of the tertiary block sometimes surpasses supply. As a result, the water level in the tertiary canal declines, leading to irrigation problems. Simulations show that irrigation problems occur for at least 20 days, resulting in a 20 % chance of water stress in fields at the tail end of the tertiary canal. The situation further aggravates when the water level in the secondary canal fluctuates substantially. In this case, irrigation problems occur on at least 30 days, and there is a 50 % chance of water stress in fields at the tail end of the tertiary canal. Irrigation problems can be somewhat reduced by lifting the tight control of the tertiary intake, but this strategy results in further over-consumption and would start a vicious circle of ever-dropping water levels in the secondary canal. The only way out is adopting a rotation schedule, which both eliminates irrigation problems and reduces water consumption. The rotation schedule does not need to be applied permanently, but can be invoked just when the water supply in the secondary canal is constraint.

Good maintenance of the tertiary canal can only realize a supplementary reduction in total water consumption in combination with a tight control of the tertiary intake. Indeed, as long as the amount of water entering the tertiary block is not controlled, reduced conveyance losses because of good maintenance can only be achieved at the expense of increased management losses. When irrigation problems occur, corresponding to low water levels in the tertiary canal, conveyance losses decrease sharply. In this case, maintenance has a negligible impact on total water consumption. Poor maintenance can however exacerbate irrigation problems at the tail end of the tertiary canal. Indeed, the combination of a smaller cross-section of the canal because of the low water level and a high resistance due to poor maintenance (Manning coefficient at 0.1, typical of heavily invaded canals (Smout *et al.*, 1997)), results in a steep slope of the hydraulic surface. Consequently, the water level at the tail end of the tertiary canal is insufficient to irrigate the fields and crop water stress ensues quickly. In contrast, good maintenance results in a near horizontal water surface, even at low levels, and as such ensures an equitable water distribution. Long-term negligence of maintenance might result in crumbling of the canal banks, altering its shape and dimensions. As stated before, simulations for different physical layouts fall outside the scope of this chapter.

10.5 Conclusion

Collective irrigation schemes throughout the world are facing pressure to increase irrigation efficiency. There is a large consensus that an important part of the solution lays in improving water management practices. In most collective irrigation schemes, water management responsibilities were transferred to farmers. The latter however face a variety of constraints that stand in the way of optimal management practices. This chapter has shown that a simulation model of water management can help to gain insights in the effectiveness of various interventions and combinations of those interventions to increase irrigation efficiency and to reduce irrigation problems under various external conditions. Combined with a thorough knowledge of the constraints that farmers face, it is possible to find an optimal mix of management practices that increase irrigation efficiency to a desired level while preserving farmers' interests as much as possible.

CONCLUSIONS

Conclusions of the case study

When the Office du Niger irrigation scheme was close to bankruptcy at the beginning of the 1980s, major reforms were imposed by the international donors who invested in rehabilitation of its infrastructure. The reforms put it on a road to success. Indeed, profitability of rice cultivation has grown, which served farmers' objective of securing a livelihood. It also serves the objectives of the central management, which are combating rural poverty and enhancing national food security. As a part of the reforms, Irrigation Management Transfer (IMT) was introduced. It reassigned responsibilities on water management at the tertiary level to farmers. Results from the field study revealed that thanks to the physical rehabilitation of the irrigation scheme and the demand-driven water supply, water delivery at the tertiary block level is adequate. Before the reforms, water shortages were common and resulted in low yields. In contrast, irrigation efficiency at the tertiary level, on average about 60 %, remains low. Furthermore, it was shown that the low irrigation efficiency brings along considerable water losses that choke the drainage system. As such, it is an important cause of the drainage problems currently affecting one third of the surface at harvest. Indeed, farmers' strategies are to maintain a constant over-supply of water to minimize the need for collective action and individual labor input. Labor is valuable to them as it comes at the price of time available for other income generating activities. This strategy conflicts with the view of the international donors and the central management of "rational" water management. They worry that the current low irrigation efficiencies and recurring drainage problems might thwart their ambitious plan to more than double the size of the irrigation scheme without a significant increase in total water consumption. Successive projects to remedy this situation did not deliver the desired results up until now, as they continuingly failed to take into account farmers' perspective. Furthermore, some projects were biased towards maintenance, which is a very visible indicator of management, but has little impact on irrigation efficiency.

In view of the ongoing expansion of the irrigation scheme, national and international competition for water and the recurring drainage problems, the concern of international donors and the central management to improve irrigation efficiency is redeemed justified. On the other hand, farmers may face physical, agronomic, economic, socio-cultural and institutional constraints that limit the possibilities of improving water management. The central objective of the research was therefore to find ways to increase irrigation efficiency while preserving farmers' interests. The approach was, in line with many scientists and practitioners around the world, to investigate how this goal could be achieved through better water management, rather than by implementing technological innovations. Benefiting from hindsight, it should be possible to answer a first question:

Is a focus on water management justified to increase irrigation efficiency while preserving farmers' interests?

In fact, during the reform process, modernization of the irrigation infrastructure and the introduction of innovative cultural practices, allowing farmers to triple or even quadruple their yields, have also realized water savings. Indeed, rehabilitation reduced conveyance losses in canals and the introduction of transplanting techniques diminished water requirements during the first part of the growth cycle. Further technological innovations might allow an additional reduction in water requirements or facilitate better water management, but for the time being, no such technologies announce themselves. Furthermore, there is a financial cost to take into account. High-tech infrastructure and its maintenance are generally expensive, and their costs should be weighed against the value of gains in labor time. Finally, they are no guarantee for success (Box 12).

Box 12 Farmers' use of modern flow control technology

There is a trade-off between flow control technology and management requirements. Infrastructure that has to be operated manually to adjust water supply to demand requires a lot of labor and certain knowledge of hydraulics (Horst, 1998; Plusquellec, 2002a). If labor is highly valued and knowledge poor, improving irrigation efficiency becomes difficult. However, sophisticated infrastructure that simplifies its use or regulates water delivery automatically is no guarantee for better use. First, even though operation is simple, sophisticated control structures often look complicated and farmers might have a completely different understanding of their use than the engineers that designed them (Scheer, 1996). For example, in the Office du Niger irrigation scheme, baffle modules were introduced at the intake of the tertiary canal. They allow farmers to estimate the incoming flow rate easily and adjust it to their demand. Some farmers however do not like them, as they give them the impression to obstruct the water flow into their canal. Consequently, they make holes in the intake to allow a free water flow. So in fact, an understanding of basic hydraulics is still needed for farmers to accept the infrastructure. Second, automatic regulation may spare labor, it also reduces farmers' and water guards' sense of control. In the Office du Niger irrigation scheme, almost all automatic regulators (fixed or floating) in the primary and secondary canals are tampered as water guards and/or farmers feel - rightly or wrongly - they do not deliver the required amount of water downstream.

In contrast, the results of this research provide two arguments for the focus on water management to increase performance. First, research results demonstrate that improved water management practices can increase irrigation efficiency from an average 60 % to about 90 %, corresponding to a decrease of actual consumption with more than a third. Indeed, most of the water losses are currently related to water management practices: excess supply to the tertiary block, excess application to the plot and spillovers in the rice basins due to the bad shape of contour dikes. The increase in efficiency can be achieved without involving irrigation problems. Indeed, through proper management practices that require some collective action but are not too arduous for farmers, irrigation efficiency can be improved with the current infrastructure and cultural practices. A second argument is that farmers' actual strategy of substituting labor by water is motivated by the high ratio of value of labor to water. Making water more valuable can however change this ratio.

Still, achieving this increase in irrigation efficiency is quite a challenge, and it is not self-evident that farmers are motivated and able to realize it. Furthermore, with water and tertiary infrastructure being common resources, they have to be able to surmount possible collective action problems. International donors pushed through IMT as a part of the reform package that breathed the spirit of increasing farmer control. Farmers were however not demanding any responsibilities on water management that extended beyond the plot level. Now, they carry the burden of increasing irrigation efficiency. Is the goal of increasing irrigation efficiency compatible with IMT?

Was IMT the right policy option for the Office du Niger?

IMT involves more than farmers being responsible for water management at the tertiary level. Part of IMT was the shift from a supply-driven to a demand-driven water delivery schedule, putting farmers at the top of the chain of decision-making. This shift has greatly improved water management from farmers' point of view, up to a point where irrigation problems have become rare. Next, concerning decision-making within the tertiary block, virtually all farmers agree that their new independence from the central management is an improvement. Even though they still have to take into account their fellow farmers' interests, they can implement water management as they think it best. Furthermore, the central management's involvement at the tertiary level in a context of increasing irrigation efficiency would require a close and thus costly follow up.

Yet, collective action remains a hurdle to be taken. About twenty years after the reforms started, collective action for water management is still underdeveloped. On the one hand, there is currently little need for collective action, with water supply being abundant and infrastructure recently rehabilitated. On the other hand, even when necessary, not all farmer groups possess sufficient social capital to establish it. For example, even though irrigation problems have become rare, they might arise after a temporary supply disruption at the secondary level, or on tertiary blocks with an uneven topography. Rules on water allocation have been observed to effectively prevent or resolve these irrigation problems. Some farmer groups however do not agree on such rules, or cannot enforce them due to the ineffectiveness of peer pressure, the only enforcement mechanism currently available. Hence, even when required in the context of increasing irrigation efficiency, it is far from sure that farmers will engage in collective action. Overall, IMT seems the best option on the condition that farmers' water management is strengthened, and impediments for establishing collective action are lifted.

What should be done next?

The following recommendations to strengthen farmers' water management and to enhance the prospects for collective action result from the research:

1. *Incentives are needed to increase the value of water to farmers*. Today, most farmers have little incentives to invest in rational water use. Even as water becomes scarce because of an expansion of the irrigation scheme, farmers with a favorable plot location will still be able to minimize their labor input at the cost of vast water losses. Others will then inevitably suffer from shortages and falling yields. Therefore, incentives are needed to increase the value of water to all farmers, so that all will rationalize its use. Volumetric water pricing is a well-known incentive and applied in many irrigation schemes throughout the world. Other measures could involve physically limiting the water delivery, or sharing the benefits of an expansion of the irrigation scheme made possible by increased efficiencies with the farmers. Any measure or incentive would however involve quantifying water deliveries at some point, which is costly, involves many practical constraints and requires sound procedures (both technical and organizational) to make sure that data are correct (Vandersypen, 2006). The Office du Niger's unfavorable layout creates some challenging trade-offs. In particular, the lower the level at which water deliveries are measured, the more effective incentives can be. Indeed, incentives at a collective level induce free riding on other farmers' efforts, which erodes their effectiveness. In the short term, practical constraints are such that measuring water deliveries is only realistic at the tertiary or even secondary level. In that case, collective action will be needed to monitor and sanction free riding. A thorough reflection including

both the central management and farmers is required to come up with the right measures and incentives.

2. *Agricultural policy needs to support full-time rice farming*. It can be expected that with time, social capital will develop and a mentality shift towards assuming collective responsibility will take place, lifting current obstacles for collective action. The trend of diversifying income however thwarts this evolution, as the importance of water management decreases when farmers have to allocate their time and effort over multiple activities. It seems doubtful that IMT could be compatible with a model of part-time farming. Agricultural policy measures might reverse the trend towards part-time farming and thus enhance the prospects for collective action. Measures could include lifting bottlenecks in financing, input supply and technical assistance. These measures will boost the profitability of rice farming and lower the need to sustain different sources of income. Regulations concerning new plot allocations should furthermore favor full-time farmers.

3. *Water User Associations need to evolve in order to enhance their effectiveness*. Water User Associations (WUAs) were set up in the irrigation scheme to fill the power vacuum left by IMT. Although they could provide a much-needed platform for institutionalizing collective action, they currently suffer from a lack of effectiveness. In order to redress their current flaws, some evolutions are required. First, farmers should be allowed to adjust structures and procedures of their WUA to their needs and possibilities. This might imply making room for oral and ad-hoc agreements that respond to specific situations. Second, support of existing authority, present at the village level, should be sought to enhance the legitimacy of WUAs, which is insufficient at present. When village leaders are involved in the WUAs, they can bring in their authority and as such might increase their effectiveness. Third, WUAs should dispose of a watertight sanctioning system. When disputes over sanctions cannot be resolved within the WUA, or even by the village leadership, the WUA should be able to appeal to an outside authority for final settlement. While the legal system implies too much of a barrier for many farmers, the central management possesses the necessary authority and is close to farmers.

4. *Farmers need training and decision support on water management*. While farmers generally appreciate their newly won autonomy, they do not yet feel in full control of water management, because they lack the necessary knowledge and understanding. This might make them unable to respond adequately to the incentives put into place to increase efficiency or to make full use of the structures and procedures offered by WUAs. Training and decision support are thus indispensable to make farmers' water management work. Furthermore,

awareness of the consequences of different water management practices (such as for example the link between over-irrigation and drainage problems) might motivate them further for rational water management. To optimize the effectiveness of training and decision support, the following points need consideration. First, the information transferred needs to take into account the practical and social constraints that farmers face. Particularly, parameters that farmers can change should be presented as variable, but parameters over which farmers have no influence should be presented as fixed. Second, the information should be targeted towards those aspects of water management that matter most for performance and are the easiest to organize and implement. Third, the audience of extension officers should include those who do not take part in the existing patterns of information transfer, but play an important role in water management, such as wage laborers employed by part-time farmers.

Given their importance, this research has developed two types of tools for training and decision support. The first tool consists in training material in the shape of extension posters and a trainers' manual. The second is a simulation model of water management, which provides an analytical tool that allows finding the best mix of practices that increase irrigation efficiency to a desired level while preserving farmers' interests. The results have been translated into guidelines. These tools have been presented in a in a workshop uniting farmers, extension officers, the presidency of the central management and international donors involved in the irrigation scheme. The positive reactions confirmed the necessity of training and training material on water management and validated the approach for their development.

Lessons learnt for scaling-up the case study to other irrigation schemes

The process of IMT in the Office du Niger, the way it was implemented, its successes and flaws and the subsequent reality of farmers' water management are quite typical for other irrigation schemes in Africa or even worldwide. From the case study, the following lessons can be drawn that are also relevant for other situations.

1. Throughout the world, IMT departed from the assumption that once given the responsibility, farmers would automatically invest in "rational" water management, which from the point of view of central managements and donors generally implies efficient water use. Farmers however balance their highly valued labor input against the benefits of increasing irrigation efficiency. The fact that increasing irrigation efficiency is not necessarily "rational" from a farmers' point of view is not yet fully realized by donors and scheme managers. The subsequent measures they take to address the disappointing outcome furthermore often build on the wrong assumptions of how water management can increase

efficiency and thus miss their mark. As they have a more distant and neutral perspective, researchers can play a beneficial role in the process of IMT by setting the problem statement right and providing negotiation support to the various stakeholders.

2. In many government built irrigation schemes, farmers originating from different communities and with no social ties share a common water source and irrigation infrastructure. In addition, they were completely excluded from management until IMT. Under these conditions, traditional forms of organization and sources of authority are hard to find. Consequently, IMT often leaves a power vacuum hampering collective action for water management. In response to this situation, WUAs are set up as new legalities to fill the power vacuum, but when they by-pass the few existing sources of authority, they cannot fulfill their intended role. In an African context, the village leadership usually provides a strong authority. The central management, which WUAs are nevertheless meant to replace, also provides an important source of legitimate leadership. In order to make WUAs work, they should be involved in WUAs, even if it might contradict principles of democratic representation favored by international donors and NGO's that usually implement them.

3. Looking at the example of successful farmer management in indigenous irrigation schemes, IMT departed from the assumption that sufficient local knowledge is present for farmers to become managers, and capacity building has so far omitted training on water management. However, in government built irrigation schemes, most farmers arrived with no hydraulic culture, as they originated from rain fed agriculture. Farmers' exclusion from management impeded the emergence of local knowledge on water management and a hydraulic culture. Consequently, local knowledge on water management principles and processes is scarce and it lessens farmers' actual control of water management. The Office du Niger case study has learned that farmers embrace opportunities to acquire knowledge and understanding of water management. Indeed, it permits them to fully and wisely use the powers transferred to them by IMT, as it gives them confidence that they will be able to respond to actual and future challenges. Capacity building of farmers and WUAs in the light of IMT is on top of the agenda of many donors and practitioners (World Bank, 2006; Van Hofwegen, 2006; UNDP, 2006). Training and decision support on water management should be a priority in that context. The tools designed in the frame of the research for training and decision support are quite specific for the case of the Office du Niger. The approach on which the development of the tools is based are however relevant for other irrigation scheme facing the challenge of improving irrigation efficiency in a context of IMT.

Interest of the research approach

The research approach of this work contains an analytical and an applied component. The analytical part aims at acquiring an understanding of farmers' water management. The applied part answers to the challenge of translating the results of the analysis into practical guidelines and tools that support farmers' water management. A merit of the approach lies in the combination of these two. Of course, the development of guidelines and tools builds on the results of the analysis. Conversely, the objective of translating the results of the analysis into tools also benefits the analysis itself, as it forces the researchers to focus on what is both important and realistic.

For the analytical component, an analytical framework is developed that allowed (1) putting the problem statement right, (2) assessing the impact of different management practices on performance, (3) discerning the practical and socio-economic constraints of water management and its potential for improvement and (4) understanding how the wider social forces might help or hinder actual and future developments in farmers' water management. The use of both quantitative and qualitative methods proved essential. A quantitative approach substantiates facts and relations resulting from the analysis, while through a qualitative approach, the wider context of these facts and relations can be understood.

For the applied component, examples of extension posters and a trainers' manual were designed, as well as a simulation model for water management. As such, the research is not limited to theoretical reflections, but also shows how farmers' water management can be improved. The main merit of these tools is that they are scientifically founded and on account of the preceding phase of analysis, benefited from an understanding of both the technical and social reality of the irrigation scheme. Both the tools and the approach to develop them were validated in a workshop uniting all stakeholders.

Perspectives for further research

This research has enhanced understanding of the process of IMT and farmers' water management and resulted in the development of tools for training and decision support. The findings and results raise some additional questions that could be tackled by future research activities or projects.

1. A doctoral research is a relatively short-term project, and allows no full validation of the recommendations that were formulated. The implementation of these recommendations will undoubtedly reveal new problems and challenges requiring new answers. As IMT

proceeds and farmers' water management evolves, the input of research could continuously refine, adjust or complement the recommendations made.

2. Irrigation has an important impact on the environment, altering natural habitats, influencing soil processes and affecting the quality of surface and groundwater. Consequently, the ongoing dynamics in the Office du Niger irrigation scheme might have important environmental consequences. Particularly, the influence of the expansion of the irrigated surface, the changes in water management practices and possible groundwater use (see Box 6) on the level of the water table and related processes such as salinisation and alkalinization should be assessed.

3. The simulation model was built to answer specific questions of particular importance in the irrigation scheme. A modeling approach is however most interesting when it is used in close collaboration with stakeholders, results are validated and presented and give rise to new questions. A presentation of the modeling approach to the stakeholders in a workshop has raised their interest in the approach. It would be worthwhile to further develop and complete the simulation model together with the stakeholders.

4. In the frame of the research, examples of extension posters and a trainers' manual were designed. Before the posters and manual can be used in actual training sessions, they need to be translated in Bambara, the local language, tested and adapted. Finally, a training campaign for extension officers has to be organized and procedures should be prepared for the extension officers to implement the training sessions. During a workshop in which the posters and trainers' manual were presented and discussed with all stakeholders, enthusiastic reactions led to the agreement to organize the remaining steps in the near future.

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Appendix 1
Calculation procedures of the simulation model

Water level in the tertiary canal

The water level (H) in a section i of the canal is the result of flows in and out of the section during a time step Δt:

$$H_{t,i} = H_{t-1,i} + \frac{Q_{in,i} - Q_{fc,i} - Q_{eff,i} - Q_{loss,i} - Q_{in,i+1}}{B_i \cdot X_i} \cdot \Delta t \qquad [m]$$

With: Q_{in} = Flow entering the intake of the tertiary canal [m³/s]

Q_{fc} = Water consumption by field intake [m³/s]

Q_{loss} = Flow leaving the section of the tertiary canal through overflow [m³/s]

Q_{eff} = Flow leaving the section of the tertiary canal through percolation, evaporation and leaks [m³/s]

B = Width of the water surface in the section [m]

X = Length of the section [m]

The simulation starts at a moment (t_0) and proceeds with steps (Δt) of 1 second until t_{end}. Decisions can however only be taken at the beginning of each hour or each day. t_0 and t_{end} correspond to the start and end date of the simulation period, and a day starts at 6 AM in the morning. The user can set H at t_0 at either zero or the nominal water level. The flows are computed through one or several submodels that use model input and the output of other submodels. Note that H stabilizes when Q_{loss} equals the difference in incoming and the remaining outgoing fluxes and has a maximum level of H_{max} at which Q_{loss} equals the maximum difference. H will not be able to fall below zero. Tertiary canals in the irrigation scheme have trapezoidal cross sections with inclination 1:1, for which the following formulas are used:

Cross-sectional area (A)	$(B_{max} - 2H_{max}) \cdot H_i + H_i^2$	[m²]
Wetted perimeter (P)	$(B_{max} - 2H_{max}) \cdot H_i + 2H_i 2^{1/2}$	[m]
Hydraulic radius	A/P	[m]

With: H_{max} = maximal water level [m]

B_{max} = width of the canal at H_{max} [m]

Water consumption by field intakes (Q_{fc})

The water consumption by field intakes is driven by the submodel IrrigationProgram that simulates the irrigation program of the different units of the tertiary block. Next, the submodel CalculateQfc determines the flow rate per field canal. As a part of the scenario, the user needs to define the number of units per field canal with their surface, and the management practices at tertiary and field level. The irrigation program is influenced by the rules on water distribution that are applied on the tertiary block. These rules limit the number of field canals irrigating.

IrrigationProgram

This submodel determines how many units are irrigating, which units irrigate, and the irrigation requirement of irrigating field canals. The number of units irrigating equals m + n. m is the number of units irrigating the day before but with irrigation requirements ($Q_{fc,req}$) still being positive (taking into account a certain margin), and which are allowed irrigation on that day according to the rules on water distribution (IrrigationPermission = true; see below). n is the number of units starting irrigation on that day.

(a) *Units continuing irrigation from the day before.* The irrigation requirement is calculated at field canal level and is updated by the submodel CalculateQfcReq. When m is known, the irrigation requirement remaining from the day before is increased with a certain amount for all irrigating units in case of water crisis, but cannot exceed the maximum irrigation dose.

(b) *Units starting irrigation on that day.* n is the result of a random procedure and will de determined through a binomial probability distribution which takes into account the average irrigation frequency applied in the tertiary block and the maximal number of field canals possibly irrigating. The latter depends on the application and type of rules on water distribution applied in the tertiary block (Submodels IsWaterCrisis and IrrigationPermission).

$$p(n) = \frac{\text{MaxUnits}!}{n!\,(\text{MaxUnits} - n)!} \cdot f^{\,n} \cdot (1 - f)^{\text{MaxUnits} - n}$$

With: n = the number of units irrigating on that day

MaxUnits = the maximum number of units likely to irrigate

f = average irrigation frequency applied in the tertiary block

The average irrigation frequency is determined by dividing the sum of net irrigation requirements (I_{net}) and field losses (FieldLoss) by the average irrigation dose (Dose).

$$f = (I_{net} + \text{FieldLoss})/\text{Dose} \qquad [\text{day}^{-1}]$$

I_{net} is calculated at tertiary block level and is a function of the cropping calendar, selected through the model input, weather conditions and soil and crop characteristics. When few units are transplanted, I_{net} will be very low, which gives results that are very similar to the real world situation (with fewer units possibly irrigating, but with higher irrigation requirements per unit) and simplifies data input considerably. Field losses are added to the irrigation requirements, and are caused by percolation through contour dikes of the paddy basins, breaches etc. They are considered constant and expressed as mm/day. The level of field losses and the average irrigation dose depend on farmers' management practices at field level, which is model input. Management practices at field level are assumed homogeneous over the tertiary block. In accordance with design standards of the irrigation scheme, it is also assumed that irrigation can be finished in one day. If in practice, this is not the case, m already compensates for the extra units needing irrigation.

(c) *Which units irrigate at which dose?* For m, the units and dose are already determined. For n, the model selects the units that are irrigated last and have the permission to irrigate. At the start of the simulation, the submodel ShakeUpLastIrri assigns randomly to each of the field canals a unique date (prior to the start date of the simulations) of the last irrigation. The model remembers the date of the last irrigation for each unit. A unit that continues irrigation from the day before cannot be assigned again. Similarly, it is impossible to assign irrigation to the management unit selected for a close follow-up. The irrigation dose for these units is determined by management practices at field level (input) and is increased with a certain amount for each day of water crisis. Once again, it cannot exceed a maximum dose. The doses of irrigating units are added to the irrigation requirement of their corresponding field canals.

CalculateQfc

The ingoing flow rate of the irrigating field canals (Q_{fc}) is calculated hourly for field canals with positive irrigation requirements. Depending on farmers' irrigation practices, irrigation will be interrupted from 6 PM until 6 AM the next morning. The field canals to which this rule applied are determined by model input. Q_{fc} is a function of the difference in water level of the tertiary canal (H) and field canal (h). It has a maximum ($Q_{fc,\ max}$) linked to the characteristics of the infrastructure as given by model input. The water level in the field canal corresponds to the level required to dominate the water level in the rice fields and is a program parameter. Supposing that the water level in the fields drop in times of water shortage, this level is reduced proportional to the duration of a water crisis. It has a bottom value (also a program parameter) below which irrigation is no longer possible. In summary:

if $H \geq h$ $$Q_{fc} = Q_{fc,\,max} \quad [m^3/s]$$

if $h > H > h$ $$Q_{fc} = 0.65 \cdot S_{wet} \cdot \sqrt{(H - h) \cdot 2 \cdot 9.81} \quad [m^3/s]$$

if $H \leq h$ $$Q_{fc} = 0 \quad [m^3/s]$$

With: S_{wet} the wet cross section of the field canal intake:

if $H \geq D$ $$S_{wet} = \frac{\pi}{4} D^2 \quad [m^2]$$

if $H < D$ $$S_{wet} = \left(\frac{D}{2}\right)^2 \cdot \left[\mathrm{ArcCos}\left(1 - \frac{2H}{D}\right) - 2 \cdot \sqrt{\frac{H}{D} - \left(\frac{H}{D}\right)^2} \cdot \left(1 - \frac{2H}{D}\right)\right] \quad [m^2]$$

with: D = diameter of the field canal intake (m^2)

CalculateQfcReq

The irrigation requirement is calculated at field canal level, supposing that irrigation deliveries are evenly distributed among all irrigating units of the field canal. It is updated every hour as follows:

$$Q_{fc,req,t} = Q_{fc,req,t-1} - Q_{fc} \cdot eff \cdot \Delta t \quad [m^3]$$

with: eff = irrigation efficiency of the field canal taking into account application losses

Application losses occur during irrigation and increase the necessary time and amount of water to apply the required dose of the field canal on the day of irrigation. They depend on farmers' management practices at field level, and in particular monitoring of irrigation. It has been observed that when farmers are not present during irrigation, over-application in certain basins with water flowing to neighboring basins and eventually the tertiary drains is frequent.

IrrigationPermission

IrrigationPermission determines whether a certain field canal has the permission to irrigate on a certain day, depending on the collective rules in use on water distribution. Depending on model input, these rules will be applied (i) continuously, (ii) in times of water shortage in the tertiary canal (represented by the model as the output of the submodel IsWaterCrisis being true) or (iii) never. One out of three types of rotation can be selected:

- Daily rotation: the field canals allowed to irrigate vary every day; each has only one day of irrigation per week
- Two-daily rotation: the field canals allowed to irrigate vary every two (or three) days, each has two (or three) days if irrigation per week
- Three-daily rotation: the field canals allowed to irrigate vary every three (or four) days, each has three (or four) days if irrigation per week

At the start of the simulation, every unit is assigned a specific weekday on which it is allowed to irrigate when rules are applied using a certain algorithm. This is that such that only neighboring units irrigate on the same day.

WaterCrisis and IsWaterCrisis

WaterCrisis is a parameter that increases each time the average water level of the tertiary canal is below a certain threshold. If the average water level rises above another threshold, WaterCrisis is reset to zero. These thresholds depend on the dimensions of the irrigation canal as determined by model input. If WaterCrisis exceeds the value WaterCrisisMax, IsWaterCrisis will be set at "true". The value of WaterCrisisMax is set by model input, with a higher value meaning that the strategies responding to a water crisis are applied more quickly.

Flow entering the tertiary canal through the tertiary intake ($Q_{in,1}$)

The flow entering the tertiary canal is determined by the water availability at secondary level, the opening of the valve, and the type and dimensions of the intake. The water supply at secondary level is expressed in terms of height above the sill of the intake and ranges from 0 (for a water level at or below the level of the sill) to a value corresponding to the maximum flow rate of the intake. Water supply at secondary level is model input. The type and dimensions of the tertiary intake are model input as well. The opening of the valve is piloted by the submodels OpenTertiaryIntake and CloseTertiaryIntake, which depend on farmers' decision rules. The intake is opened only once a day (in the morning). It can be closed every hour during the daytime. CloseTertiaryIntake is ran also just before opening the intake.

OpenTertiaryIntake

This submodel consists of a set of decision rules that determine the opening of the tertiary intake (O), defined by its width (Table A.1). The maximal opening (O_{max}) depends on the dimensions of the intake (model input). The rules are the same for all farmers and independent of management practices. They use H_{t-1} and the water supply at secondary level as criteria. The same rules apply for different types of infrastructure but will have different outcomes. Modular intakes can be adjusted with small steps, while the semi-modular intake is either open at its maximum width or closed. Whenever $Q_{fc,req}$ of one of the field canals is positive, the intake will be opened.

Table A.1 Decision rules regarding the opening of the tertiary intake

Criterion[1]	Rule Modular intake[2]	Rule semi-modular intake
$H > H_{max} - k1$	$O = Q_{max, fc} * 10$	$O = O_{max}$
$H_{max} - k1 > H > h_{max} + k2$	$O = O_{t-1} + Q_{max, fc} * 10$	$O = O_{max}$
$H < h_{max} + k2$	$O = O_{max}$	$O = O_{max}$
Water level secondary canal < k3	$O = O_{max}$	$O = O_{max}$

[1] k1, k2 and k3 are program parameters
[2] For the type of intake common in the study area, 1 cm of opening of the intake corresponds to 1 l/s

CloseTertiaryIntake

CloseTertiaryIntake consists of decision rules that determine the closing of the tertiary intake (Table A.2). In reality, different farmers have different decision rules. In the model, decision rules will be attached to field canals, as decisions are triggered by irrigation activities at field canal level. The mix of rules is determined by model input and an algorithm assigns the rules to the field canals at the start of the simulation. The rules are put into practice whenever one of the field canals stops irrigating. At every time step during daytime, the model evaluates whether a field canal stops irrigating (because $Q_{fc,req} = 0$ or t = 6 PM), and then looks up the decision rule attached to the field canal. If more than one field canal stop irrigating, rules with a higher number have priority over the lower numbers.

Table A.2 Decision rules regarding the closing of the tertiary intake

Rule	Criterion[1]	Rule Modular intake	Rule semi-modular intake
1	In all circumstances	$O_t = O_{t-1}$	$O_t = O_{t-1}$
2	if $O_{t=6AM} > O_{t=5AM}$ (else rule 1)	$O_t = O_{t-1} - q_{max, fc}$	not applicable
3	if $Q_{fc;req} = 0$ for all field canals (else rule 2)	$O_t = 0$	$O_t = 0$
4	if t = 6PM (else rule 3 and wait until 6PM)	O = 0	O = 0

[1] Rule 4 is assigned exclusively to field canals on which irrigation is interrupted between 6 PM and 6 AM the next morning (see submodel CalculateQfc)

CalculateQin0

In function of the opening of the tertiary intake and the water level in the secondary canal, the submodel CalculateQin0 computes the flow rate entering the intake. Standard hydraulic formulas are used.

Flow entering a section from a neighboring section ($Q_{in, i}$)

Water enters a section from a neighboring section when its water level is lower. The flow rate can be calculated using the Manning-Strickler formula:

$$Q_{in,i} = \frac{1}{n} \cdot \frac{2}{3} \cdot T \cdot \left(\frac{H}{H_{max}}\right)^{1/2} \cdot H \cdot \left(\frac{2H}{3}\right)^{2/3} \cdot \sqrt{H_{i-1} - H_i} \qquad [m^3/s]$$

With: n = roughness coefficient

The roughness coefficient is assumed to be homogeneous over the length of the tertiary canal and depends on the maintenance level (model input).

Conveyance losses (Q_{eff})

Conveyance losses are assumed to occur evenly throughout the length of the canal. They are a function of the maintenance level (worse maintenance corresponds to higher losses) and the water level (through the width of the water surface in the canal). Q_{eff} varies linearly from zero when the water level equals zero, and $Q_{eff, max}$, for $H = H_{max}$. Q_{eff} is calculated using H_{t-1} and variations of H during the time step are not considered:

$$Q_{eff} = C_{eff} \cdot B_i \cdot X_i \qquad [m^3/s]$$

With: C_{eff} = constant determined by the maintenance level

The larger the conveyance losses, the more difficult it will be to maintain a sufficiently high water level in the tertiary canal when supply at secondary level is limited.

Management losses (Q_{loss})

Security structures in tertiary canals are overflow weirs that are placed either at the end of the canal, or at each field canal intake. They are placed at a certain distance below the canal banks. Their placement and dimensions are model input. As long as H < the level of the overflow weir (H_{weir}), Q_{loss} will be equal to zero. Otherwise, the flow is determined as follows:

$$Q_{loss} = 1.8 \cdot l \cdot (H - H_{weir})^{1.5} \qquad [m^3/s]$$

With: l = length of the overflow weir (m)

H_{weir} = level of the overflow weir (m)

Water storage in a management unit

The simulation model computes the water storage (WS) of a unit at a certain moment by adding to the water storage at a previous moment the aggregate water flows to and from the unit over the period in-between:

$$WS_{t+1} = WS_t + (IRRI + P - ETa - DP - LOSS)\Delta t \qquad [mm]$$

Water storage is the amount of water stored in and/or on a soil. It can be positive, zero or negative:

WS > 0 → saturated soil with water layer; WS = level of the water layer (mm)

WS = 0 → saturated soil without water layer

WS < 0 → unsaturated soil; WS = root zone depletion (with saturation as the reference):

$$\text{Root zone Depletion} = WS_{U,\,sat} - W_{r,\,act} \qquad (mm)$$

$$WS_{U,\,sat} = 1000\ \theta_{sat}\ Z_R \qquad (mm)$$

$$WS_{U,\,act} = 1000\ \theta_{act}\ Z_R \qquad (mm)$$

With: θ_{sat} = water content of the root zone at saturation (m^3/m^3);

θ_{act} = actual water content of the root zone (m^3/m^3)

Z_R = depth of the root zone (m)

WS cannot be larger than the height of the contour dikes, and not lower than the level of the water table during the rainy season, which are program parameters. The simulation of the water storage in the management unit is done simultaneously with the simulation of the water level in the tertiary canal, and starts and ends on the same moment. The water storage is calculated daily. Since irrigation activities for the selected unit are piloted in a different way than the other units, and since these activities determine water deliveries by the field canal, the selected unit should be the only unit depending on its field canal. As for the tertiary canal, the flows are computed through one or several submodels that use model input and the output of other submodels.

IrrigationUnit

The submodel IrrigationUnit triggers the irrigation events. This decision is based on the actual water storage of the unit, which is the basis of farmers' decision rules on irrigation. As long as the water storage of the unit remains above the minimum target level, the irrigation demand will be zero. When the water storage falls below the minimum target, the irrigation demand will be equal to the difference between the actual water storage and the maximum target level, and is added to the water requirement of the corresponding field canal. Both targets evolve with the growth stage of the rice crop, and an input file specifies their values as a function of the number of days after transplanting. They can be increased in function of the state of land leveling (linked to management practices at field level as selected by model input) and the output of the WaterCrisis submodel, but have a maximal value. The irrigation demand can be limited by the rules on water allocation.

Irrigation

This submodel calculates the actual irrigation dose delivered to the unit (IRRI) as a function of the total amount of water delivered by the field canal and the surface of all irrigating units. If the dose did not fulfill the requirements of the unit, irrigation will be continued the following day using the procedures of IrrigationProgram.

Rain, evapotranspiration and percolation

All rain (P) is supposed to be effective. The submodel Rain therefore only retrieves the daily rainfall from an input file. Actual evapotranspiration (ETa) is calculated as the product of the reference evapotranspiration (ET0) and a crop factor (Kc). Two-weekly averages are used for ET0, which are contained in an input file. Kc, a program parameter, is supposed to be constant throughout the growing season. When $WS < 0$, actual evapotranspiration decreases following the calculation methods of Allen *et al.* (1998). Deep percolation (DP) is also constant throughout the growing season, except if $WS < 0$ when it is zero. As the vast majority of soils have similar physical soil properties, DP is a program parameter.

Losses

Losses are the result of excess flows into the unit, compared to its water storage and the physical layout. In the scope of the simulations under consideration, the model will only allow for excess rainfall and excess irrigation at night.

Model input

The model has default entries for each of the management practices and external variables. However, in the Main Menu (Figure A.1), a different scenario can be composed by clicking on the Hydro, Layout and Management buttons in the Scenario panel. In the Simulation panel, the start and stop date of the simulation period are selected, as well as the position and plant date of the simulated unit. Check boxes give the user the choice to specify whether the tertiary canal is empty at the start of the simulation and whether allocation rules are applied continuously or not. A text box allows the user to specify the number of times the model should run.

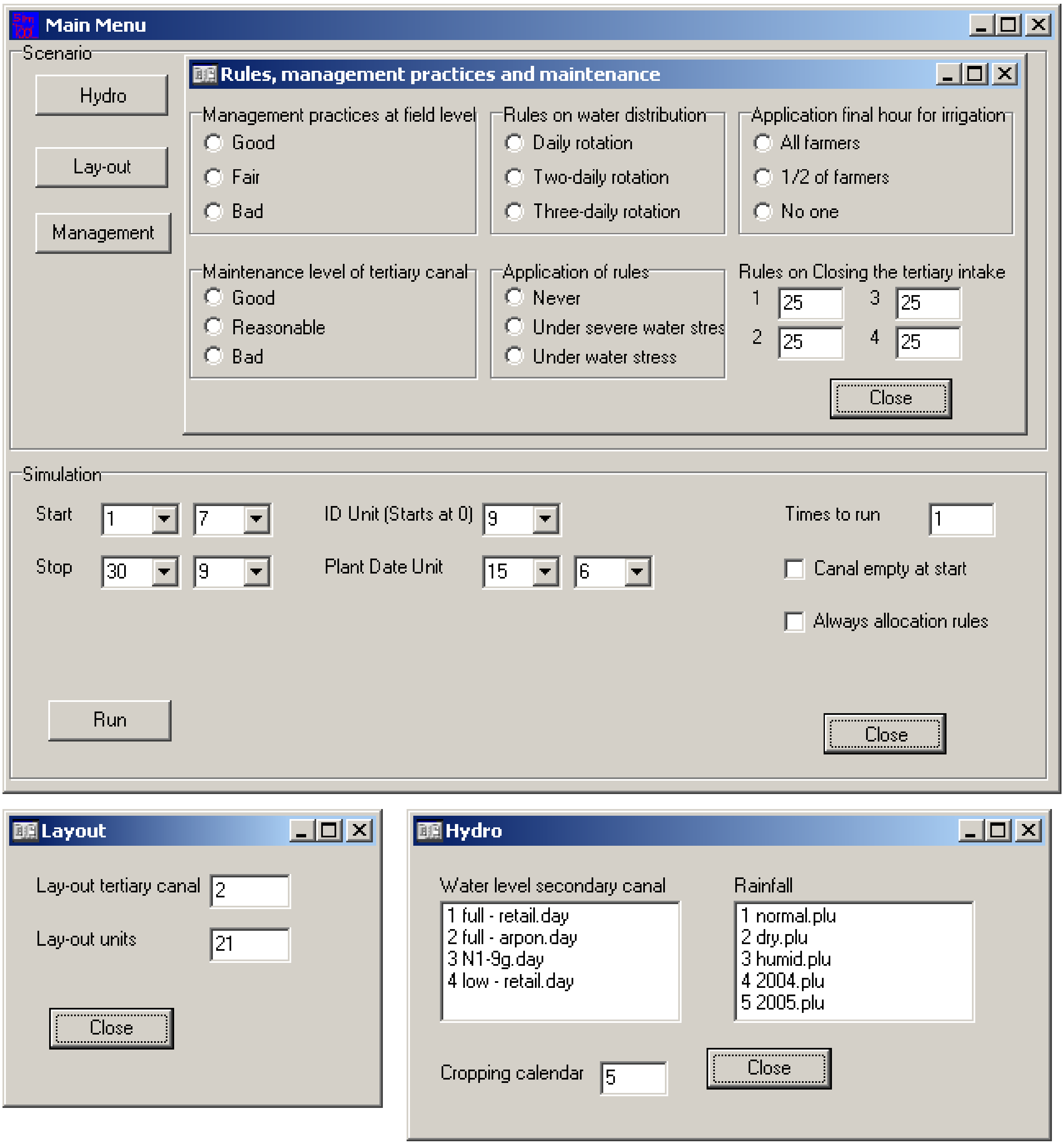

Figure A.1 Screen shot of the different input menus

Farmers' management practices

1. *Farmers' decision rules regarding the closing of the tertiary intake:* The mixture of rules on the closing of the tertiary intake is entered as percentages, such that the sum is always 100 %. In addition to these rules, the user can specify the proportion of field canals interrupting irrigation between 6 PM and 6 AM the next morning. As rule 4 implies this interruption, the user should check for coherence in the input.

2. *Maintenance of the tertiary canal:* The maintenance level can be good, reasonable or bad and determines the Manning coefficient and the efficiency coefficient (Table A.3)

Table A.3 Value of the parameters linked to the maintenance level of the tertiary canal

Maintenance level	Manning coefficient	Efficiency coefficient
Good	0.01	$12\ 10^{-8}$
Reasonable	0.05	$35\ 10^{-8}$
Bad	0.1	$58\ 10^{-8}$

3. *Farmers' decision rules regarding water distribution within the tertiary block:* These decision rules contain two aspects: the type of rules and the application of rules. If rules are only applied in case of water shortage, the severity of water stress necessary to trigger the rules is taken into account by the value of WaterCrisisMax to which WaterCrisis is compared. Two choices appear in the input:

- Under water stress: WaterCrisisMax = 47;
- Under severe water stress: WaterCrisisMax = 95

Finally, on some blocks, rules are never applied. This is taken into account by a third option in the input. Since some other decision rules are based on the occurrence of water crises, WaterCrisisMax will be set at 47 (as in the first option). However, the submodel IrrigationPermission will always allow irrigation for all field canals on all days.

4. *Farmers' management practices at field level:* Farmers' management practices at field level determine the water losses in the field (FieldLoss), which will be added tot the irrigation requirements, the irrigation dose (Dose), the degree of land leveling (LandLevel) and the application efficiency of irrigation (Eff). Roughly speaking, bad management practices increase the irrigation requirement and thus the chance of irrigation problems. Values are shown in Table A.4.

5. *Cropping calendar:* The simulation model uses ten-daily irrigation requirements as input. These are calculated using the calculation procedures explained in Vandersypen *et al.* (2006). There is just one input file with in each column the ten-daily irrigation requirements

for a specific cropping calendar and rainfall. In the dialog box Hydro, the user fills in the number of the column to use in the simulation.

Table A.4 Value of the parameters linked to the management practices at field level

Management practices	FieldLoss (mm)	Dose (mm)	LandLevel (mm)	Eff
Good	1	80	0	0.9
Fair	1.5	70	50	0.8
Bad	2	60	100	0.7

External factors

1. *Water supply of the secondary canal:* The water level of the secondary canal can vary daily and is entered in an input file. Each scenario has a different file. All input files are shown in a list box in the Hydro dialog box.

2. *Rainfall:* Daily rainfall data are needed to simulate the water layer in the selected unit. Similar to the water level in the secondary canal, the data are contained by input files that can be selected in a list box in the Hydro dialog box.

3. *Type and dimensions of infrastructure:* Two input files specify the type and dimensions of the infrastructure. The first contains data on type and dimensions of the tertiary canal. Every column represents a different canal, and the number of the column is asked in the dialog box Layout. The second contains information on the number and surface of units for each field canal. There are one or more files for each canal type. In the dialog box Layout, the number of the file should be entered.

Output

The output of the model is written to text files and consists in the evolution (per hour) of the water level in the tertiary canal for each of the nodes and the evolution (per day) of the water level in the selected unit (see Figure 10.7 for an example). In addition to this output, the model will calculate certain performance indicators:

- *Total water consumption:* The model calculates the total water consumption at the tertiary intake over the simulation period per hectare (m^3/ha).
- *Water losses:* At tertiary level, water is lost though field losses, application losses, conveyance losses and management losses. Apart from reducing overall irrigation efficiency, field losses, application losses and conveyance losses increase the probability of irrigation and drainage problems on a canal. As they are predetermined by the scenario (for conveyance losses, also the water level plays a role), they are however not considered

for the performance indicator, which is based solely on management losses. They are expressed as the total management losses over the simulation period per hectare (m³/ha).

- *Irrigation problems:* Irrigation problems occur whenever the water level in the tertiary canal drops below a certain threshold. When the water level drops even further, irrigation is no longer possible. The model calculates the total number of time steps for which the water level drops below 30 cm, 20 cm and 10 cm. The performance indicators then express these values in days, by dividing by 24.
- *Water stress at field level:* The model calculates the average water level in the selected unit. Depending on the degree of land leveling, water stress can occur on some parts of the unit when the average water level is quite low. The model therefore calculates the number of days with a water level lower than 10, 5 and 0 cm (with the minimum target level being higher than these levels).

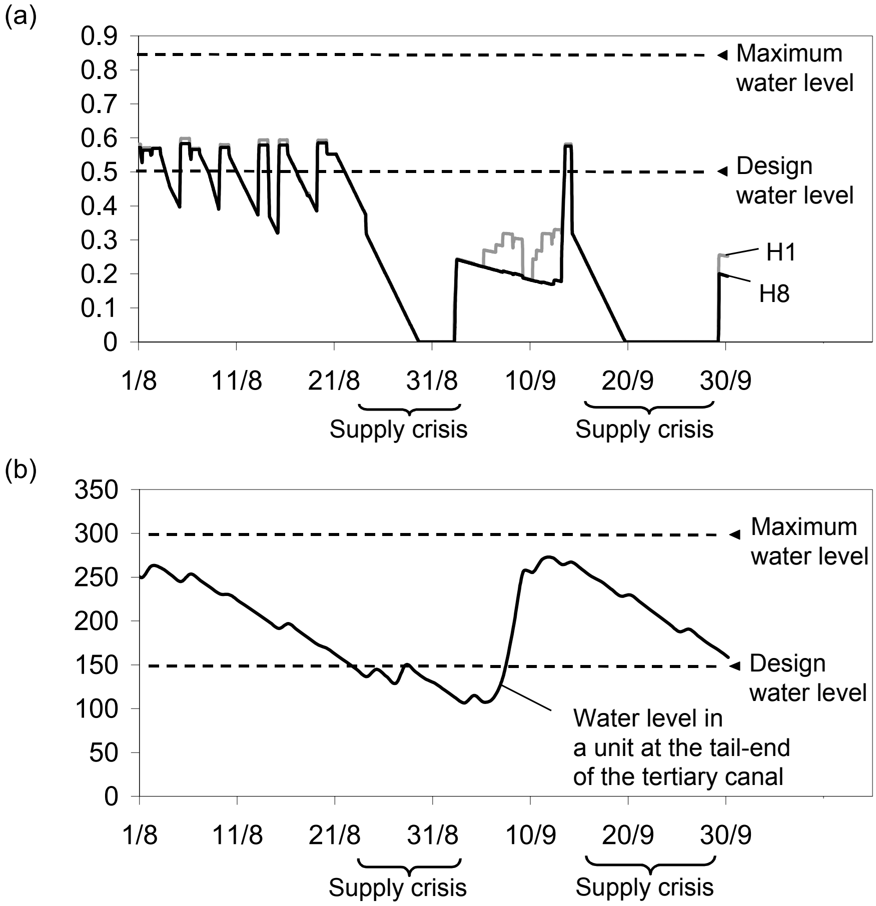

Figure 10.7 Evolution of the water level (a) in the tertiary canal and (b) in the selected unit for Block A (see Chapter 10)

Appendix 2
Closed question survey

In standardized closed question surveys, the order and phrasing of questions are fixed, and the interviewed persons are obliged to pick their response from a set of pre-determined answers. This approach is appropriate when results are treated quantitatively. This appendix describes the closed question survey administered to quantify performance of water management from a farmers' point of view (Chapter 5). The questionnaire is translated from French into Bambara. On the next pages, the parts of the French version of the questionnaire concerning the background data, irrigation assessment, conflicts and rice production are inserted. Interviewers administered the questionnaires in personal interviews of about one hour. This method might give rise to survey errors. Below, the different sources of errors are described flowing the classification by Groves (1989), along with strategies to circumvent them.

Errors of non-observation

Errors through non-observation arise when no information is obtained from certain respondents and/or questionnaire items. (1) *Non-coverage* occurs when units in the population have no chance of being selected by the survey sample. The target population of this survey consists the in plot holders of the sample of 36 tertiary blocks. As complete lists of farmers are available from the register of water fees, the sample frame leaves no room for non-coverage. (2) *Unit non-response* occurs when selected plot holders cannot be located or refuse to participate in the survey. People in the irrigation scheme are usually cooperative and only one refusal occurred. Farmers have no addresses, but most live in the village corresponding to the secondary canal. With the instruction of fellow-villagers, they could be located easily. Twice, it was impossible to locate non-resident farmers, who were then replaced by other non-resident farmers. (3) *Item non-response* refers to certain questions not being asked or answered. A good layout of the questionnaire and training of interviewers made these rare.

Errors of observation

Errors of observation occur when information noted down on the questionnaire is false. (1) The *interviewer* can be a source of error when responses are made up or falsified, questions are asked wrongly or his style or relation with the respondent influence responses. In order to reduce these errors, two interviewers were selected carefully based on their reputation of honesty. Furthermore, they participated in a testing phase in which question phrasing and layout were improved and trained using the final version of the survey. Finally, the interviewers cultivated a rice plot themselves, which should favor a good relation with the respondents. These strategies appeared successful as an extensive control of the survey could largely confirm the results for most parts of the questionnaire. (2) *Respondents* are another source of error, as they might misunderstand or misinterpret questions, or give wrong answers on purpose. The first is avoided through careful question wording and by adding short introductions to the different parts of the questionnaire explaining the purpose of the questions. To avoid the second, a series of strategies are applied. First, in a general introduction of the questionnaire, the interviewer explained that the survey is organized by a local research center, which is popular in the area (see Box 1). This should avoid antagonism of the respondents. Second, the introduction furthermore states that the survey is not linked with a development project, which could induce the respondent to answer strategically and overstate certain problems in the hope that the "project" would then come to solve them. Third, special attention is given to the introduction and wording of questions on the presence and respondents' involvement in conflicts.

As farmers are usually embarrassed about them, conflicts make for a sensitive topic. As such, the word "conflict" was replaced by the softer "misunderstanding", and question phrasing suggested that conflicts are commonplace and the respondents are probably involved in them (presumed behavior), which are common strategies to put respondents at ease. In this case, the strategies did not work. Only a handful of farmers answered positively on the presence and their involvement in conflicts, while interviews on conflict mediation suggest that they occur rather frequently. The control of the survey furthermore revealed several falsified answers. The best strategy to tackle sensitive questions is to guarantee anonymousness. This was however impossible because interviews were administered face-to-face. Furthermore, in order to make a control possible, names were noted down at the start of the questionnaire. Lastly, interviewer effects must have played a role. For one of the two interviewers, positive responses were virtually absent.

Conclusion

Overall, the survey can be considered successful. Careful preparation of the questionnaire and the selection and training of the interviewers could avoid many sources of error. Only the results on sensitive questions, in particular on conflicts, were unreliable and the topic has therefore been treated in a more qualitative way.

Appréciation des EXPLOITANTS sur la gestion de l'eau au niveau tertiaire

Méta-données

AVANT L'INTERVIEW

Identification

partiteur : ....
arroseur : ....
numéro de l'exploitation : ....

chef d'exploitation : ....
répondant (indiquée par le chef d'exploitation / autre) :
→ nom : ....
→ relation avec le chef d'exploitation : ....
....

Tentatives de contact

	raison de reporter l'interview	date et heure du prochain rendez-vous
1		
2		
3		
4		

Déroulement de l'interview

enquêteur : ....
date : ....
heure initiale de l'interview : ....

APRES L'INTERVIEW

heure finale de l'interview : ....
autres personnes présentes pendant l'interview :

	nombre	relation avec le répondant
1		
2		
3		
4		

Description du lieu de l'interview :

- ❑ concession du répondant ....
- ❑ place publique du village ....
- ❑ champ du répondant ....
- ❑ autre → ....

Description des circonstances de l'interview :

- ❑ tranquille ....
- ❑ quelques dérangements ....
- ❑ beaucoup de dérangements ....
- ❑ ....

Description de l'attitude du répondant :

oui	non	
		intéressé
		motivé
		questions bien comprises
		coopératif
		méfiant
		autre →

....
....
....
....
....
....
....

Le répondant s'attendait à de l'aide financier ou autre ?

- ❑ oui
- ❑ non

INTERVIEW

Irrigation

Dans cette partie de l'interview, on veut parler sur l'irrigation. On veut comprendre si pour vous personnellement, il est facile d'irriguer le champ ou si des fois il est difficile et pourquoi. On parle toujours au même champ qui est sur l'arroseur concerné.

1. Avez-vous eu facilement de l'eau pendant la campagne ?

- ❑ toujours
- ❑ la plupart du temps
- ❑ rarement

2. Quand vous avez eu un problème d'eau :

- ❑ vous étiez le seul à souffrir
- ❑ tout le monde avait le même problème
- ❑ Il n'y a pas eu des problèmes d'eau

3. Pour pouvoir prendre l'eau facilement, il faut :

oui	non	
		que l'arroseur soit un peu plein seulement
		que l'arroseur soit très gonflé
		que les autres exploitants ne prennent pas d'eau

SI DEUX DERNIERS SONT COCHES : Est-ce que :

- ❑ une des deux conditions doit être présente au même temps : l'arroseur soit très gonflé OU les autres exploitants ne prennent pas d'eau
- ❑ toutes les deux conditions doivent être présentes au même temps : l'arroseur soit très gonflé ET les autres exploitants ne prennent pas d'eau

4. Par rapport à cette campagne seulement, pour avoir l'eau, il a fallu dans la pratique :

COCHER SI OUI	Est-ce que c'est le cas			est-ce que ça vous a dérangé		
	tou-jours	sou-vent	des fois	beau-coup	un peu	pas du tout
Ouvrir le champ seulement et l'eau coule						
Souvent d'abord demander l'eau à l'aiguadier (ou le chef d'arroseur)						
D'abord nettoyer l'arroseur (partie des autres exploitants)						
Bien surveiller le champ pour que les autres ne ferment pas la rigole ou la prise du champ						
Se concerter avec les autres exploitants						
Autre →						

5. Il y a d'autres exploitants sur l'arroseur à part de vous. Si vos voisins n'avaient pas cultivé leur champ pendant la campagne précédente, et donc n'avaient pas pris d'eau, est-ce que vous auriez eu :

- ❑ beaucoup moins de problèmes
- ❑ les même problèmes

Déroulement de la campagne

Maintenant, on veut parcourir les différentes étapes de la campagne pour demander si vous étiez satisfait de l'irrigation pendant cette période et connaître les problèmes qui se sont produits.

6.Vous étiez satisfait de l'irrigation :

oui	non	
		Pendant la pépinière
		Pendant la pré-irrigation
		Pendant le repiquage
		Pendant la période de croissance
		Pendant la période de remplissage des grains de riz

7. On peut penser de plusieurs causes des problèmes d'irrigation. On a fait une petite liste qu'on va parcourir, et pour chaque possibilité vous pouvez dire si oui ou non ça a joué. A la fin, vous pouvez indiquer encore d'autres causes qui n'étaient pas encore dans la liste. Est-ce que :

COCHER SI OUI	Le problème a duré		Est-ce que ça vous a dérangé		
	beau-coup	un peu	beau-coup	un peu	pas du tout
Il y avait une crise d'eau ou coupure au niveau du partiteur					
L'eau était coupée au niveau de l'arroseur					
Il y avait problème d'eau à cause de la topographie					
L'arroseur n'était pas bien nettoyé					
Tout le monde prenait l'eau en même temps					
Les autres exploitants ont fermé la prise d'arroseur					
Les autres exploitants ont fermé la prise de rigole ou de champ					
Les autres exploitants ont fermé / ouvert le barrage sur l'arroseur					
Autre →					

8. A cause du problème d'irrigation :

oui	non	
		la qualité du riz a baissée
		les coûts de production ont été plus hauts
		le rendement n'était pas bon
		votre programme de travail était dérangé
		il y a un autre désavantage, notamment : ....

Aspects sociaux

Maintenant, il y a quelques questions par rapport aux règles qui existent autour de la gestion de l'eau. Des fois, les exploitants se sont convenus sur des règles sur la gestion de l'eau, comme le tour d'eau, ou l'entretien de l'arroseur pendant une certaine période.

Souvent, il y a des mésententes entre les exploitants d'un arroseur sur la gestion. Pendant les années passées, est-ce que vous avez fréquemment des mésententes sur :

COCHER SI OUI				sont-ils graves ?		ça vous a dérangé			il en a eu pendant cette campagne ?	sont-ils graves ?	
	très	un peu	pas	très	pas très	beau-coup	un peu	pas du tout		très	pas très
L'irrigation											
Le drainage											
L'entretien des infrastructures											
Le démarrage de la campagne											
Le gaspillage d'eau											
Autre ?											

Rendement

Pour terminer, on voudrait passer au sujet de la production. On a quelques question sur combien vous avez gagné cette campagne et si vous êtes content de ce résultat. On s'intéresse à ce sujet seulement pour pouvoir comparer les différents cas des différents arroseurs qu'on étudie. On ne va pas du tout communiquer ces informations à l'Office du Niger. Quoi que soit votre résultat, il est important que vous nous disiez la réalité du terrain. On parle toujours seulement par rapport au champ sur l'arroseur concerné.

1. Combien d'hectares avez-vous exploité sur cet arroseur ? ....

2. Sur cette surface, combien de sacs de paddy avez-vous eu pendant la campagne précédente ? ....

3. Par rapport à la **quantité** de la récolte, êtes-vous satisfait de ce résultat ?

❑ oui
❑ plus ou moins
❑ non

→ On peut penser de plusieurs causes du faible résultat. On a fait une petite liste qu'on va parcourir, et pour chaque possibilité vous pouvez dire si oui ou non ça a joué. A la fin, vous pouvez indiquer encore d'autres causes qui n'étaient pas encore dans la liste. Est-ce que :

oui	non	cause principale	
			Il y a eu une peste ou maladie
			Il y a eu une manque d'eau
			Il y a eu des dégâts causés par les animaux (rats, souris ou oiseaux)
			Le champ était noyé au moment du repiquage
			Le champ était mouillé pendant la récolte
			Il y a eu une manque d'engrais
			Il a plu pendant la récolte
			Le sol est fatigué
			Autre, notamment : ....

Parmi ces causes, qu'est-ce qui a été la cause principale ?

4. Par rapport à la **qualité** de la récolte, êtes-vous satisfait de ce résultat ?

❑ oui

❑ plus ou moins

❑ non

→ On peut penser de plusieurs causes du faible résultat. On a fait une petite liste qu'on va parcourir, et pour chaque possibilité vous pouvez dire si oui ou non ça a joué. A la fin, vous pouvez indiquer encore d'autres causes qui n'étaient pas encore dans la liste. Est-ce que :

oui	non	cause principale	
			Il y a eu une peste ou maladie
			Il y a eu une manque d'eau
			Il y a eu des dégâts causés par les animaux (rats, souris ou oiseaux)
			Le champ était noyé au moment du repiquage
			Le champ était mouillé pendant la récolte
			Il y a eu une manque d'engrais
			Il a plu pendant la récolte
			Le sol est fatigué
			Autre, notamment : ....

Parmi ces causes, qu'est-ce qui a été la cause principale ?

5. Par rapport à la couleur des grains de riz lors du décorticage, est-ce qu'il y avait :

❑ pas de décoloration

❑ une décoloration faible

❑ une décoloration forte

On est arrivé à la fin de l'interview. Si vous voulez, vous pouvez encore ajouter des choses dont vous n'avez pas encore eu l'opportunité d'en parler.

....

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Merci beaucoup pour votre collaboration !!

Appendix 3
Semi-structured questionnaire surveys

In semi-structured interviews, the interviewer uses a list of open questions that serves as a guide and checklist during the exchange. Both the exact formulation and the order of questions can be adapted to the flow of the interview. In this setting, interviewed persons are expected to express their viewpoints more freely and precisely, which makes it appropriate to obtain detailed, in-depth and/or sensitive information. Interview methods and techniques are based on Flick (1998). The interviews were assisted by an interpreter, with whom the translation (French to Bambara and Bambara to French) of questions and specific terms were elaborately discussed beforehand. Before each interview, the context and purpose of the research in general and the interview in particular were communicated in an introduction. Below, the key questions (in French) of the various series of interviews are given.

Stakeholder analysis (Chapter 2)

- Quel est votre rôle au sein de /dans la zone Office du Niger ?
- Quels sont vos objectifs (personnels / par rapport à l'Office du Niger) à court terme / à long terme ? Comment ces objectifs peuvent-ils être réalisés ? Quelles contraintes rencontrez-vous pour réaliser ces objectifs ?
- Comment jugez-vous l'organisation / la performance de la gestion de l'eau ?
- Quelles sont les enjeux majeurs par rapport à la gestion de l'eau ? Comment ces enjeux peuvent-ils être adressés ?

Assessment of irrigation and drainage problems in preparation of the closed question survey (Chapter 5)

- Avez-vous eu des problèmes d'approvisionnement en eau / de drainage ? (Où, quand)
- Quelles en sont les causes/ les conséquences ?
- Comment avez-vous géré le problème ?

Organization of water management at the tertiary block level (Chapter 5)

- Est-ce que sur votre arroseur, il y a des règles qui parlent sur le moment juste de vos prises d'eau ? (Expliquez) Si oui :
  - Quelles sont ces règles ?

- Est-ce qu’elles sont appliquées depuis le début des travaux champêtres jusqu’à la fin ?
- Les règles sont-elles toujours respectées ? Qu’est-ce qui se passe quand une personne ne respecte pas les règles ?

Si non :

- Est-ce qu’on peut prendre de l’eau quand on veut ?
- Comment est-ce que c’est réglé quand plusieurs personnes veulent avoir l’eau à la fois et il n’y en a pas assez ?
- Qu’est-ce qu’on fait quand quelqu’un vous dérange pendant l’irrigation ?

* Est-ce que vous vous parlez pour déterminer la quantité d'eau d’irrigation dont vous aurez besoins dans les jours à venir ?
* Des fois, il n’y a pas assez d’eau dans l’arroseur pour irriguer sa parcelle. A qui est-ce que vous vous adressez le plus souvent pour demander l’eau ?

Interviews with village leaders on the social and historical back-ground of the village (Chapter 7)

* Quand le village a-t-il été crée ? Comment a-t-il été colonisé ?
* Quelle est la composition actuelle de la population ? Comment les gens s’entendent-ils au sein du village ?
* Comment l’AV/TV (coopérative) fonctionne-t-il ? Y-a-t-il d’autres coopératives actives dans le village ? Comment pouvez-vous décrire leur relation avec l’AV/TV ?

Interviews with village leaders on their role in water management (Chapter 7)

* Quel est votre rôle au sein du village ? Quel est votre rôle concernant la gestion de l’eau ?
* Quelle est votre relation avec les exploitants, chefs d’arroseur, OERTs, chef de partiteur, CPP, AV/TV, agents et chefs de l’Office du Niger, … ?
* Existe-t-il une chose au sein d’un arroseur qui est pareille à l’autorité d’un chef de village ? Quelles sont les caractéristiques d’un bon chef d’arroseur ? Qui parmi les chefs d’arroseur de votre village possède ces caractéristiques ?

Interviews on water management practices (Chapter 10)

* Comment est-ce que vous déterminez qu’il est temps d’irriguer le champ ?
* Quelle est la hauteur de la lame minimale ? C’est la même pour tous les paysans ? Qu’est-ce qui fait la différence ?

- Combien d'eau ajoutez-vous lorsque vous remplissez le champ ? Est-ce qu'une journée suffit pour remplir le champ ? Si non, que faites-vous ? Comment pouvez-vous contrôler la quantité ajoutée ? Assistez-vous à l'irrigation ? Est-ce que vous irriguez pendant la nuit ?
- Quelle est la hauteur des diguettes ? Est-ce que c'est la même pour tous les exploitants ? Qu'est-ce qui fait la différence ?
- Quelle est la fréquence avec laquelle vous partez au champ ? Vous estimez que c'est beaucoup par rapport aux autres exploitants ? Quelles catégories utiliseriez-vous pour juger la fréquence de partir au champ ? Est-ce qu'il y a des jours spécifiques sur lesquels vous ne partez jamais au champ ? La fréquence normale, peut-elle être influencé par les circonstances ? Les quelles ?
- Au moment d'une crise d'eau, est-ce que vous adaptez vos stratégies d'irrigation ? Allez-vous essayer de remplir le champ pour pouvoir faire face à la crise ? Allez-vous augmenter la fréquence avec laquelle vous partez au champ ?
- Combien de temps passe d'habitude entre deux irrigations ? Qu'est-ce qui peut l'influencer ?
- Lorsque vous irriguez, combien d'autres exploitants sur votre arroseur irriguent d'habitude au même moment ? Est-il possible que plusieurs exploitants irriguent au même moment et avec la même rigole ?
- Combien de vidanges faites-vous pendant la campagne ? Quand ? Pourquoi ? Qu'est-ce qui détermine si vous faites une vidange ? Est-il toujours possible de faire une vidange quand vous voulez ? Pourquoi pas ? Vous assistez lorsque vous faites une vidange ?
- Comment déterminez-vous la date de récolte ? Qu'est-ce qui peut influencer la date de récolte ? Combien de temps êtes-vous prêts à attendre avec la récolte si le champ ne peut pas être vidangé ?
- Quand se passe-t-il la dernière irrigation ? Combien de jours avant la récolte ? Qu'est-ce qui peut influencer cette date ?

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